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An Investigation of a Developmental Sequence of the Standing Long Jump Using Multidimensional Scaling

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Daniel James Wilson

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AN INVESTIGATION OF A DEVELOPMENTAL SEQUENCE OF THE STANDING LONG JUMP USING MULTIDIMENSIONAL SCALING

By

Daniel James Wilson

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

AN INVESTIGATION OF A DEVELOPMENTAL SEQUENCE OF THE STANDING LONG JUMP USING MULTIDIMENSIONAL SCALING

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The purpose of this study was to investigate a staging sequence of the standing long jump. Kinematic, kinetic, and anthropometric data on thirty-three subjects (25 males and 8 females) between the ages of 4 and 7 years was collected. Variables included those parameters that were identified by Seefeldt et al. (1972) as differentiating between stages of development in their whole-body configuration model of the standing long jump. High-speed cinematography, force platforms, and various anthropometric instruments were used for data collection.

Data was reduced and analyzed using multivariate analysis of variance, univariate (ONE-WAY) analysis of variance, multidimensional scaling, and individual difference scaling. Multivariate and univariate statistics were used to determine differences between stages of motor skill proficiency in the standing long jump between all variables. Multidimensional scaling and individual difference scaling were used to investigate the validity of the staging sequence as a construct for the assessment and instruction of the motor skill.

The results indicated that the main observable variables that differentiate between the stages of motor ability were (1) position of the body at the moment of landing, (2) the distance jumped, (3) the resultant acceleration of the thighs, (4) the resultant acceleration of the trunk, (5) the resultant acceleration of the arms, (6) the resultant acceleration of the forearms, and (7) the resultant segmental force contributions of the forearms.

The results of the multidimensional scaling and individual difference scaling suggested that the set of variables identified by Seefeldt et al. (1972) did not produce a clear differentiation between stages, and the variable(s) that underlie the progression of an individual from one stage to another could not be identified using this set of variables. Therefore, a subset of five variables were selected for further interpretation based upon their ability to differentiate between stages as evidenced by the univariate tests. This subset included (1) position of the body at landing , (2) acceleration of the thighs, (3) acceleration of the trunk, (4) acceleration of the arms, and (5) acceleration of the forearms.

Using this subset of variables, the individual difference scaling procedure was repeated and revealed a linear pattern of stage membership. This pattern showed a progression form stage 1 to stage 4 and was complimented by a cluster analysis that showed excellent discrimination between stages. Age was found to correlate significantly with the subject's stimulus weights generated by the individual difference scaling. This lead to the conclusion that the progression from one stage to another is an age-related phenomenon. Multidimensional scaling was found to be a useful tool to investigate the construct of a developmental motor sequence. The implications of these results for teachers of the fundamental motor skill (standing long jump) were discussed.

DEDICATION

To James and Shirley Wilson, my parents,
for instilling in me a belief in myself,

you gave me that gift,
now I give this,

we shared a dream for my future,
we attained that dream together,

this manuscript belongs to us,
I love you.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to the following individuals who have made so profound an impact on my life and contributed so generously to the completion of this manuscript.

First and foremost, I must thank my committee chair, advisor, and most importantly, my friend, Dr. Eugene Brown. Your unfaltering support during my graduate career has provided the model by which I may always measure my achievement as a scholar and my humanity toward those who may seek my guidance.

To Dr. Vern Seefeldt and Dr. John Haubenstricker, who have given so generously of their time and provided the resources by which I could pursue my educational goals, thank you so much. I count myself among the very many who have been so fortunate as to have shared in your knowledge and kindness.

To my committee members, Dr. Richard Houang and Dr. Marty Ewing, who have helped me delve through the world of statistics, your insight and time have been invaluable, thank you.

Finally, a very special expression of appreciation and love to Holly for bringing such joy and happiness to my life.

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Chapter I

INTRODUCTION

Relationships between the qualitative assessments of human physical activity by motor developmentists and the quantitative approach taken by biomechanists is a recent development in the history of investigation into motor behavior. Study of motor behavior, that may be accredited to the early 1920's and intensified during the 1930's, was primarily the work of physicians specializing in child development (Cunningham, 1927; Shirley, 1931). Physical performance was also being observed and evaluated during this period by physical education specialists interested in developmental changes (Bliss, 1927). These early investigations into the performance of motor activities were generally descriptive in nature. Qualitative assessments of gross body movements and anthropometric measurements were the predominant methods of investigation.

During the time of the second world war, there was a decline in the investigation of motor development of children. This decline lasted throughout the 1940's and 1950's. Not until the late 1960's was there an increased interest in the processes that underlie the development of motor skills in maturing children (Haubenstricker & Seefeldt, 1986). This renewed interest brought with it new perspectives into the evaluation of motor skills and a subsequent focusing on scientific methodology that sought to formulate and test theory.

The emergence of motor development and motor learning as topics of research interest, during the late 1960's and early 1970's, produced publications that introduced new approaches to the assessment of motor progress and to the teaching of physical education (Roberton & Halverson, 1977; Seefeldt, 1979). Among these approaches was the theory that 'stages' of development could be used to order and classify changes in body configurations and/or movement patterns of parts of the body. These stages were identified, ordered, and evaluated on the basis of kinematic and kinetic variables associated with motor performance. This theory serves as the focus of this investigation.

Stage Theory

Stage theory, as it is viewed by motor developmentalists, lies within a theoretical framework that may be viewed as 'classical stage theory' (Roberton, 1982). In this sense, it is a classical theory in that data gathering is directed by theory and theory subsequently modified by the data obtained. This approach is the same framework used to develop Piaget's (1976) stages of cognitive development and Kohlberg's (1963) stages of moral development. Staging sequences, therefore, are based upon a solid theoretical framework and developed and modified according to the scientific method.

Primary within stage theory is the relative timing, ordering, and contributions of the movements of body segments as they relate to the overall physical performance. The stages are viewed as developmental levels that may be identifiable with a particular skill. Each of the stages may in turn represent progress along an underlying continuum toward the mature performance of the skill. According to Seefeldt (1979), the identification of a staging sequence is a consequence of the three prerequisite conditions that teachers of physical activity and motor skills must possess. These conditions are

1) a knowledge of the developmental sequences for a variety of fundamental motor skills,

2) the ability to identify the various levels of development as children perform the skills, and

3) a knowledge of the activities and experiences that will assist the learner in moving to a more mature level.

It is the first of these conditions, knowledge of developmental sequences, that is addressed in this investigation. The remaining conditions depend upon the success of the educator in obtaining the knowledge contained in the first condition. Thus, the validity of the developmental sequences is prerequisite to identifying and assisting the learner of motor activities.

Identification of stages of motor development

Seefeldt (1979) stated that, "the study of developmental movement tasks depends on the accurate analysis of what is occurring at a given moment..." (p. 348). Therefore, in order to make use of a staging sequence for a given developmental movement, a reliable and valid method of analysis is needed. To carry out the analysis of skills, the movement of the body segments relative to one another, as well as with respect to the environment, is viewed as a biomechanical phenomenon (Seefeldt, 1979). Thus, physical activity is identified, ordered, and classified according to the mechanical determinants of the movement.

The identification of a motor development staging sequence is not the purpose of this investigation. The identification of the variables and their unique ability to determine a stage is the purpose. The ordering of the stages is, however, of critical importance. To validate developmental stages as a construct, comparisons of variables by stage will not suffice. Validation requires a process capable of considering all stages of development simultaneously and establishing the legitimacy of the order of those stages. According to Korell (1976),

> Seriation and multidimensional scaling are two procedures which might be used to validate constructs when ordering is an important consideration. Both techniques could be used to order developmental stages, course objectives, and levels of behavior in curricula. (p. 1)

For this study, multidimensional scaling has been chosen as the procedure to investigate the validity of the staging sequence of the standing long jump. This procedure results in a graphical representation of the ordering of developmental sequences to study both their validity and possible modifications. A specific statistic (stress function) is contained in multidimensional scaling to measure the relative fit of the ordering of a developmental sequence according to the parameters that comprise it.

Mechanical determinants of stages

Stages of motor development are described and assessed using a visual evaluation of temporal, positional, and mechanical variables that characterize the movements of body segments. Temporal variables include the relative timing of movements of body segments being used to aid in the performance. Positional information includes the orientation of the body relative to the ground (e.g., body lean) at takeoff and landing. Little is known of the relationship of these variables to other maturational characteristics (e.g., age).

The qualitative statements used to characterize stages of motor development include comparative statements about mechanical variables. For example, in Seefeldt et. al's (1972) four stage model of the standing long jump, the first stage is characterized by a vertical component of force that may be greater than the horizontal. In addition, the arms are described as moving backward. This motion acts to stop the momentum of the trunk as the feet extend in front of the center of mass of the body. Similar mechanical descriptions are used to characterize the other three stages of the sequence. However, it is not known whether these parameters are differentiable by stage. Mechanical definitions of stages of motor development have been used by other authors as well (Roberton & Halverson, 1977; Gallahue, 1982; Clark & Philips, 1985). Primary within the validity of all of the staging sequences is the ability of the researchers to accurately measure and quantify the determining mechanical variables. If any two stages are to be viewed as uniquely different, the characteristics of each should be measurably dissimilar.

Need for the Study

The staging sequences that have been discussed depend upon mechanical descriptions to differentiate between the individual stages. However, in practice, staging criterion are developed and utilized by qualitative methods of assessment. Where more quantitative methods have been used, the specific tools (e.g., clear screen tracing; Seefeldt, V. Personal communication, December, 1992.) allow for considerable error. The mechanical variables determining developmental sequences have not been subjected to rigorous biomechanical assessment.

Purpose of the Study

It was the purpose of this study to investigate the staging sequence of a fundamental motor skill. The standing long jump was investigated by measuring the kinematic, kinetic, and anthropometric variables that characterize Seefeldt et al.'s (1972) whole-body configuration model of the standing long jump. A two-step process of analysis consisted of (1) comparisons by stage of the variables that describe individual stages and (2) a validity study of the staging sequence as a construct for assessing and providing instruction of fundamental motor skills. Specifically, the following research questions were addressed.

Question 1. Are the stages of the standing long jump related to the maturational characteristics of age?

Question 2. Are the stages of the standing long jump related to body composition (percent body fat) and size (segmental masses)?

Question 3. Does the objective of the standing long jump (distance) differentiate between the developmental stages of the performance?

Question 4. Are the stages of the standing long jump differentiable by body orientation at takeoff and landing?

Question 5. Are the stages of the standing long jump differentiable by the contibutions of the individual body segments (acceleration, force)?

Question 6. Can stage theory as a construct be validated using multidimensional scaling?

Limitations of the Study

The results of this investigation are subject to the following limitations.

1) The sample selected for this study was not a true random sample, but consisted of volunteers obtained from a four city area. The sample consisted of 25 males and 8 females. Generalizations may therefore be limited to the characteristics held similar to this population.

2) The ability of children to perform to their maximal capabilities at young ages is suspect under the conditions of data collection for this study. A scientific setting, including flood lights, high-speed cameras and brief clothing may have hindered children from performing to their capabilities.

3) The center of mass of the body for each subject was calculated using a model that did not include the segmental masses of the hands. This resulted in a loss of approximately 1.2% of the total body mass. The resulting loss in accuracy of the center of mass of the entire body was judged to be negligible.

Definitions

Center of mass - the point about which the mass of the body may be thought to be evenly distributed.

Unfolding - a mathematical process that seeks to represent the relationships between a set of variables by producing spatial plots of various numbers of dimensions. The distance between any two variables is a measure of the strength of the relationship between them. The number of dimensions is representative of the number of underlying variables that are thought to explain the relationships between the variables. The dimensions are 'unfolded' to produce the distances in the various dimensions.

Chapter II

REVIEW OF LITERATURE

Cognitive psychologists have defined specific criteria that must be considered before using the stage construct as an explanation of age related changes in behavior. Each of these criteria will be defined and discussed as they relate to developmental changes in motor skills. According to Brainard (1978),

> To be viewed as potentially explanatory, a stage model must describe some behaviors that undergo age change, posit antecedent variables believed to cause the changes, and provide procedures whereby the behavioral changes and the antecedent variables can be independently measured. (pg. 2).

These guidelines are compatible with the five criteria of the stage construct that Piaget (1976) listed as invariant sequence, cognitive structure, integration, consolidation, and equilibrium.

Invariant sequence, or hierarchization as it is often known, has been considered by many writers (Kohlberg, 1968; Kurtines and Greif, 1974) to be the most important of the five criterion. Put into simple terms, invariant sequence is the belief that for stages to be valid, they must follow a distinct chronology or have a constant order or succession. This is not to say that all behaviors must appear in each individual at exactly the same time, but rather that each individual must, at their own pace, pass through each stage in the same order. Therefore, the importance of invariant sequence is fundamental. Without this characteristic, the stage model has no relevance to developmental constructs. Brainard (1978) was careful to note that the invariant succession of stages should be investigated for their chronology. In order to properly apply the scientific method to the question of stage theory, the stages must empirically verify their own existence. This leads one to the realization that stages must associate themselves to an underlying behavior that cannot be altered by environmental factors. Therefore, a developmental trait such as a motor activity should show a definite order of succession when studied for its chronology. To motor development specialists, this would represent the modal (most frequently observed) category of a physical skill following the proposed maturational continuum.

Cognitive structure refers to the members of a set of stages as having their own unique complement of underlying cognitive behavior. The underlying behavior responsible for the appearance of a stage would dictate that any individual within a given stage would operate on approximately the same level in other related areas (structural wholeness). Roberton (1978) has viewed this concept of structural wholeness as the unity of the internal structures and process subserving any particular stage.

Integration asserts that each stage presupposes the immediately preceding stage. Thus, the inferior becomes part of the superior. Therefore, as one achieves a higher stage, the characteristics that determined the lower stage are incorporated or integrated into the higher stage.

Consolidation refers to the gradual evolution of each stage from the one that immediately preceded it. This consolidation of stages is achieved in a continuous pattern that may not show distinct boundaries as an individual moves from one stage to the next. Often, the transition from one stage to another will show evidence of invariant sequencing in behaviors belonging to each of the stages. This transitional period in which elements of both stages are evident has been referred to as horizontal decalage by Piaget (1976).

The last criterion is equilibrium. Piaget viewed the process of maturation of cognitive development as the attainment of successive states of equilibrium, in which each successive stage was more stable than its predecessor. As a new stage is realized, the old stage falls into a state of non-equilibrium and eventually loses its distinction. An imbalance between the mental structures and the environment is supposed to cause a behavioral trait to move out of its consolidated stage into a transition, then, into the next higher stage as reorganizing structures reconsolidate.

The explanatory status of Piaget's stages is a critical issue to educators. There are numerous authors (Freud, 1930; Kohlberg, 1963; Piaget, 1976) who have cited theories that may be viewed as traditional examples of stage theory. Additionally, a number of early childhood cognitive and physical curricula, based on Piaget's theory, have been devised and tested (for reviews, see Hooper & DeFrain, 1974; Lawton & Hooper, 1978). It has been suggested in these curricula that children should never be taught skills that exceed the limits of their current stage. However, Brainard (1978) stated that, "... there is no compelling support for Piaget's hypothesis that his cognitive stages do more than describe age-related changes in behavior." (p. 180) If Brainard's analysis of Piaget's stages is correct, the rationale for using these practices may be suspect. Therefore, staging sequences used as instructional guides should be investigated for their correctness, and to determine potential underlying constructs.

Stage Theory in Motor Development

The employment of stage theory in cognitive psychology evolved into its use in motor development. This progression was natural since early researchers of motor skills were often developmental specialists from the fields of psychology and medicine (Shirley, 1931; Ames, 1937; Gesell, 1946; McGraw, 1943).

Early investigation into the sequencing of motor skills can be traced to works by Halverson (1931) and Shirley (1931). Halverson described the sequential changes that were taking place in the development of specific motor skills through a detailed recording of the first observation of rudimentary performance of these skills in infants. Shirley used the concept of an "interskill sequencing" to describe a sixteen-stage process that lead to upright locomotion. Her description of these sequences, and subsequent sequences that concentrate on other locomotor skills, focused on the order of events that could be traced as children matured.

It was later that developmentalists realized they must also study and describe the proficiency with which a given task ("intaskill sequencing") was performed in order to study the sequencing of motor tasks as possible stage constructs. A description of this proficiency, in terms of the key anatomical movements, was later provided by Godfrey and Kephart (1969). They not only classified the variables of performance as a function of a maturational continuum, but provided a checklist of those events that profiled the mature performance (see Figure 1). Motor proficiency could thus be observed, measured, and described in terms of the individual motor tasks of the body segments. These segments were then observed to change their temporal sequencing and relative efficiency to the task as the performer moved toward the mature performance. Seefeldt and Haubenstricker (1982) noted that the ultimate criterion of 'mature' performance was defined by highly skilled adult athletes. This provided the model needed for the sequencing of fundamental motor skills as a tool in defining maturational changes. Thus, motor development specialists continued to develop new 'staging' sequences for various skills. During the last two decades, numerous developmental sequences have been proposed for fundamental motor skills. Haubenstricker and Seefeldt (1986) summarized the main skills for which two or more developmental sequences have been proposed. This summary includes both interskill and intraskill models for development. Intraskill developmental models for the standing long jump have been summarized in Table 1. This table highlights the diversity of approaches used inassessing development of this skill.

Roberton (1978) pointed out that as a theory, the concept of stages in motor development is open to scientific study. However, motor development researchers seemed to accept stages as a "given" rather than a theory to be tested. Roberton further noted that the most testable aspects of stage theory are those of a universal stage sequence (same for all) and intransitivity (progression in one direction). Thus, if a sample of children were followed longitudinally and a single case was found to violate these concepts, the law would be refuted. Using this line of reasoning, Roberton (1977) conducted an investigation of the overarm throw to test this theory. She reasoned that if children go through stages in learning a motor task, they should look rather stable in their movement during the time they

Date________________ Age_________

Sex_______ Name________________

Pattern Elements Present		Deviations Noted	
____	Arms swing back as legs bend	____	No arm swing ____ back only ____ up only
____	Arms swing up as legs extend	____	Jumps to side ____ L ____ R
____	Uses two-foot take-off	____	Stumbles or falls on landing
____	Can do one-ft take-off ____ L ____ R	____	Lands on same foot
____	Straight direction	____	Can't land on 2 ft w 1 ft take-off
____	Jumps in place, same spot	____	Doesn't use arms to help
____	Brings arms down on landing	____	Uses one arm only ___ L ___ R
____	Opposition arm-leg on 1 ft jump	____	Twists or bends to side __ L __ R

REMARKS:

Examiner_______________________

Figure 1. Movement pattern checklist for jumping. From: Movement patterns and motor education (p. 162) by B. Godfrey and N. Kephart, 1969, Appleton-Century-Crofts.

are in a particular stage. Any variation in these patterns should simply imply that the individual is in a transition from one stage to an adjacent stage. Independently classifying the movements observed in each of 10 trials of throwing for 73 first-grade children, Roberton found that all children varied only to adjacent categories of arm action in the throw, and that each child had at least half of his/her trials classified into the same category. Her results agreed with the notions of a universal, intransitive stage sequence. The methodology described in Roberton's study (prelongitudinal screening) is generally accepted as a starting point for testing stage constructs in motor development.

Roberton (1982) described the procedure of prelongitudinal screening. This

Table 1
Intraskill Developmental Sequences of the Standing Long Jump

Author(s)	Number of Stages	Model
Hellebrandt, et al. (1961)	Three	Whole-body
Seefeldt et al. (1972)	Four	Whole-body
Roberton & Halverson (1977, 1984)	Three-five[1]	Component
McClenaghan & Gallahue (1978)	Three	Whole-body
Gallahue (1982)	Three	Whole-body
Williams (1983)	Four	Whole-body
Haubenstricker et al. (1984)	Four	Whole-body
Roberton (1984)	Three-five	Component
Clark & Philips (1985)	Four	Component

[1] Stages are represented for individual body segments in the component model.

screening is seen as valuable for researchers interested in studying the universal invariance of developmental sequences. Roberton reasoned that, if children were really "in" any particular stage, they should show the characteristics of that stage regularly across trials. She arbitrarily chose a fifty percent agreement rate for trials within the modal category for each child; otherwise, the movements would be too variable to be considered "in a stage". Further, if any child's trials varied away from the modal category, they should vary only to adjacent stages in a hypothesized sequence. If children could skip stages at one point in time, she reasoned that they would be likely to do so across time. If a sequence shows less than fifty percent stability or one child shows nonadjacent trial variations, it is probably not a universal, invariant sequence. This procedure provided a first-step alternative to studying a hypothesized motor sequence as a stage construct using a longitudinal approach.

Quantification of Stages in Motor Development

Seefeldt and Haubenstricker (1982) introduced a procedure for merging quantifiable data with developmental theory. In their own words, "In 1966 we began viewing movement as a biomechanical phenomenon, through which the joint actions could be identified, ordered, and classified." (pg. 311). This approach to answering the question of whether stage theory is indeed applicable to motor development bridges the gap between qualitative description and the scientific method of testing quantitative parameters. However, a fundamental problem arose in the methods used by Seefeldt and Haubenstricker and the proponents of this approach. Although viewing movement as a biomechanical phenomenon, Seefeldt and Haubenstricker used a qualitative method in describing the parameters that defined the performance. Definable statements about performance based upon qualitative data are not subject to the critical analysis and retesting of quantitative data.

The development of the qualitative stages of fundamental motor tasks have followed two different paths, each defined by its main proponents and/or originators. The first observational method for defining fundamental motor skills was outlined by Wild (1938) in a description of the sequencing of the overhand throw. This method of describing motor skills has become known as the "total body configuration method." Seefeldt and Haubenstricker (1982) detailed the strengths and weaknesses of this procedure in utilizing it as a teaching tool for the analysis and correction of motor skills. The mechanical approach taken in this method of defining stages is illustrated in the four stages of the overarm throw. Seefeldt and Haubenstricker's (1976) qualitative stages of the overarm throw are shown in Figure 2. Mechanical characteristics used as descriptors to divide these stages include components of force, direction of movement of segments of the body, contributions to momentum from segments, and the location of the center of gravity of the body. While the individual body segments serve as performance parameters for identifying stages, it is a whole or total body configuration approach that is used in this method for assessment and correction of motor performance.

The second method, proposed by Roberton (1977), is a component model of intra-task motor development. Although this method is not under investigation in this study, the basic tenants are provided here for the sake of completeness. Roberton felt that, if there were indeed stages of motor task development, these stages may occur only in the components of the skill, rather than in the total body configuration. The model of intra-task components argues that although two individuals may be identified within the same stage of development for a specific motor skill, individual components of the skill may vary between the individuals at any given time. Thus, the anatomical segments are seen to follow their own individual progression, rather than the whole-body progressing as a series of unified components.

Characteristic weaknesses are inherent in the use of both the total body configuration and intra-task component methods for defining the parameters of study. In each of these methods of staging motor skill acquisition, performance is characterized by those observable parameters that may be qualitatively assessed and described. Thus, practitioners are left without quantitatively definable parameters upon which to evaluate performance and initiate change.

Qualitative Stages of the Standing Long Jump

The use of a staging construct to explain developmental changes in human jumping behavior has been proposed in recent years. However, the identification of emerging patterns in jumping dates back to long before staging theory was introduced to the understanding of acquisition of motor skills. The mature jump was photographed by

STAGE 1	The throwing motion is essentially posterior-anterior in direction. The feet usually remain stationary during the throw. Infrequently, the performer may step or walk just prior to moving the ball into position for throwing. There is little or no trunk rotation in the most rudimentary pattern at this stage, but those at the point of transition between stages one and two may evoke slight trunk rotation in preparation for the throw and extensive hip and trunk rotation in the "follow-through" phase. In the typical stage one the force for projecting the ball comes from the hip flexion, shoulder protraction and elbow extension.
STAGE 2	The distinctive feature of this stage is the rotation of the body about an imaginary vertical axis, with the hips, spine and shoulders rotating as one unit. The performer may step forward with either an ipsilateral or contralateral pattern, but the arm is brought forward in a transverse plane. The motion may resemble a "sling" rather than a throw due to the extended arm position during the course of the throw.
STAGE 3	The distinctive pattern in stage three is the ipsilateral arm-leg action. The ball is placed into a throwing position above the shoulder by a vertical and posterior motion of the arm at the time that the ipsilateral leg is moving forward. This stage involves little or no rotation of the spine and hips in preparation for the throw. The follow-through phase includes flexion at the hip joint and some trunk rotation toward the side opposite the throwing.
STAGE 4	The movement is contralateral, with the leg opposite the throwing arm striding direction during the "wind-up" phase. There is little or no rotation of the hips and spine during the wind-up phase; thus, the motion of the trunk and arm closely resemble those of stages one and three. The stride forward with the contralateral leg provides for a wide base of support and greater stability during the force production phase of the throw.
STAGE 5	The "wind-up" phase begins with the throwing hand moving in a downward arc and then backward as the opposite leg moves forward. This concurrent action rotates the hip and spine into position for forceful derotation. As the contralateral foot strikes the surface the hips, spine and shoulder begin derotating in sequence. The contalateral leg begins to extend at the knee, providing an equal and opposite reaction to the throwing arm.

Figure 2. Developmental sequence for the overarm throw as proposed by Seefeldt & Haubenstricker (1976).

Muybridge in 1887, using multiple cameras to capture both anterior and posterior views. Since that time, both the understanding of the developmental patterns of jumping and technology for assessing these patterns have advanced. However, the search for the underlying reasons behind the development of jumping behavior has made very little progress in physical education.

Developmentalists continue to explore the emerging patterns of physical activity. The mechanical bases of movement are one area of study. The physiological bases for those patterns are also being explored. This includes the connection between motor skill development and neurological development. Hellebrandt et al. (1961) discussed in detail the connection between neurological development and the emergence of the 'fundamental' motor skills in children. The introduction of reflex movement began to show the connection between the maturation of the neurological system and the acquisition of motor ability. In jumping, tonic neck reflexes have received credit as the integrators of performance (Hellebrant et al., 1961). As Hellebrandt et al. (1961) stated, "the jump pattern is recognizable long before strength is sufficient to propel the body very effectively in space." (pg. 23) Thus, the patterns displayed by children in their jumping behavior followed a similar physiological development. Continuing with this premise, Hellebrandt et al. (1961) developed descriptions of the various patterns viewed in children's jumping as their patterns matured. The sequences they proposed may be viewed as the first staging sequence for the standing long jump.

Several staging sequences for the standing long jump have been proposed since the work of Hellebrandt and his colleagues. Wickstrom (1970), Seefeldt et al. (1972), Roberton and Halverson (1977), McClenaghan and Gallahue (1978), Gallahue (1982), Williams (1983), and Clark and Philips (1985) have all proposed developmental sequences. Although any of these staging schemes may prove useful to the individual instructor of motor skills, it is the sequences of Seefeldt et al. (1972) and Roberton and Halverson (1977) that have received the greatest interest in recent years. This is due, at least in part, to the introduction of Roberton and Halverson's staging sequence as a consequence of viewing the total body configuration methodology used by Seefeldt et al. as only partially explanatory of the individual differences in observed body segment contributions.

Roberton (1977), citing data reported for the overarm throw, showed that development did not take place in total body changes; rather, certain components of the body's movements changed while others did not. Citing this data as evidence for the invalidity of the intra-task whole-body stages proported by Seefeldt et al. (1972), she developed her own "component model of intra-task motor development." By this approach, two children moving through the same stages would show a different combination of components at any given time. Roberton concluded by stating that these 'stages' also lack the broadness needed to fulfill the concept. To avoid semantic confusion, she suggested that a better word would be 'steps."

The sequence proposed by Seefeldt et al. (1972) represents a traditional approach to classifying stages of locomotion known as "between-task" (see Figure 3). This term arises from the fact that each stage represents a different task for the entire body. In other words, each stage is viewed as a unique structure of movements along the developmental continuum. This continuum is demonstrated in Shirley's (1931) stages of locomotor development in which "scoot backward" is a vastly different task from the eventual "walk alone". This method of describing a task along a maturational continuum, and describing the development of movements from the first appearance of the action until mature form is reached, is demonstrated in proposed stages by Seefeldt et al. (1972) and Wickstrom (1977). This staging methodology has been termed "intra-skill stages" (Seefeldt et al., 1972) or "intra-task stages" (Halverson et al., 1973).

Roberton's (1977) proposal for stages within "components" of a particular task deals with the development of body segments and/or areas (e.g., leg or arm action) within the task. This approach was expanded by Roberton and Halverson (1977) in their intra-task component model. Roberton (1978) discussed the question of which approach to staging theory makes the most sense in motor development in terms of the "structural wholeness" staging criterion . Using the example of a child in "stage 1", Roberton pointed out that the child should show the characteristics of that stage in the movements used for both throwing

STAGE 1	Vertical component of force may be greater than horizontal, resulting jump is then upward rather than forward. Arms move backward, acting as brakes to stop the momentum of the trunk as the legs extend in front of the center of mass.
STAGE 2	The arms move in an anterior-posterior direction during the preparatory phase, but move sideward (winging action) during the "in-flight" phase. The knees and hips flex and extend more fully than in stage one. The angle of take off is still markedly above 45 degrees. The landing is made with the center of gravity above the base of support, with the thighs perpendicular to the surface rather than parallel as in the "reaching" position of stage four.
STAGE 3	The arms swing backward and then forward during the preparatory phase. The knees and hips flex fully prior to take-off. Upon take-off the arms extend and move forward but do not exceed the height of the head. The knee extension may be complete but the take-off angle is still greater than 45 degrees. Upon landing, the thigh is still less than parallel to the surface and the center of gravity is near the base of support when viewed from the frontal plane.
STAGE 4	The arms extend vigorously forward and upward upon take-off, reaching full extension above the head at "lift-off". The hips and knees are extended fully with the take-off angle at 45 degrees or less. In preparation for landing the arms are brought downward and the legs are thrust forward until the thigh is parallel to the surface. The center of gravity is far behind the base of support upon foot contact, but at the moment of contact the knees are flexed and the arms are thrust forward in order to maintain the momentum to carry the center of gravity beyond the feet.

Figure 3. Seefeldt et al.'s (1972) whole-body configuration model of the standing long jump.

and striking. Thus, the movement patterns of any stage should be seen in several tasks at once, giving it vertical (hierarchical) structure. In this view, Shirley's staging sequence would not meet the criterion of a stage construct as her levels of locomotor development are primarily an age ordering of tasks. In Wohlwill's words (1973), there "is no more reason to label each of these responses as a 'stage' than there is, for example, to apply that term to places on the itinerary of a bus line" (p. 193).

Mechanical Analysis of the Standing Long Jump

The mechanical analysis of the standing long jump has received little attention by researchers in comparison to qualitative assessment. Studies that have used a mechanical approach to study jumping ability have primarily focused on the takeoff phase of the performance. This type of analysis has provided valuable information on the differences in takeoff parameters as a function of maturational level. Tables 2 and 3 list reported mean values for kinematic and kinetic parameters, respectively, of the standing long jump at takeoff.

Investigation of the mechanical parameters of the standing long jump has shown that mature form is reached at an early age. Horita et al. (1991) noted that body configuration, takeoff angle, and reflex activity have all the components of mature form by school age (6 or 7 years). Roy, Youm and Roberts (1973) showed that the kinematic patterns of some basic skills such as throwing, running, kicking, and jumping had already been established by school age (5 years). Focusing specifically on the vertical and horizontal components of force, impulse, and power generated during the propulsive phase of the jump, Roy et al. (1973) investigated the assumption that the standing long jump would similarly show muscular patterns capable of mature form. A definite trend was found in maximal horizontal velocity and both horizontal and vertical components of maximal power. These measures increased with age. The maximal horizontal acceleration tended to remain constant from the age of 10 years. Resultant velocity of the center of gravity of the body at take-off increased from seven through 16 years of age. This increase was primarily due to an increase in the horizontal component of velocity, as the vertical

Table 2
Mean Values for Kinematic Variables Studied
in the Standing Long Jump at Takeoff

Variable	Value	Variable	Value
Velocity at center of mass		Acceleration at center of mass	
vertical	7yrs; 5.1 (n = 15)[a]	vertical	7 yrs; 43.8 (n = 15)[a]
	10 yrs; 5.1 (n = 15)		10 yrs; 42.8 (n = 15)
(ft/sec)	13 yrs; 5.2 (n = 20)	(ft/sec/sec)	13 yrs; 43.3 (n = 20)
	16 yrs; 6.1 (n = 5)		16 yrs; 37.9 (n = 5)
(m/sec)	20 yrs; 1.83 (n = 12)[b]	horizontal	7 yrs; 22.6 (n = 15)[a]
	6 yrs; 0.96 (n = 8)		10 yrs; 31.4 (n = 15)
		(ft/sec/sec)	13 yrs; 33.1 (n = 20)
	3 yrs; 1.2 (n =19)[c]		16 yrs; 37.9 (n = 5)
	4 yrs; 1.8 (n = 19)		
	5 yrs; 1.7 (n = 23)	Distance	
	6 yrs; 1.9 (n = 22)		
	7 yrs; 2.0 (n = 19)	horizontal	3 yrs; 44.7 (n = 19)[c]
			4 yrs; 69.9 (n = 19)
horizontal	7 yrs; 7.4 (n = 15)[a]	(cm)	5 yrs; 89.9 (n = 23)
	10 yrs; 8.7 (n = 15)		6 yrs; 109.0 (n = 22)
(ft/sec)	13 yrs; 9.2 (n = 20)		7 yrs; 109.9 (n = 19)
	16 yrs; 11.4 (n = 5)		
		Projection angle[d]	
(m/sec)	20 yrs; 3.27 (n = 12)[b]		
	6 yrs; 2.01 (n = 8)		3 yrs; 38.9 (n = 19)[c]
			4 yrs; 38.7 (n = 19)
	3 yrs; 0.9 (n = 19)[c]	(deg)	5 yrs; 31.7 (n = 23)
	4 yrs; 1.2 (n = 19)		6 yrs; 31.2 (n = 22)
	5 yrs; 1.4 (n = 23)		7 yrs; 30.2 (n = 19)
	6 yrs; 1.2 (n = 22)		
	7 yrs; 1.2 (n = 19)		
resultant			
	3 yrs; 1.6 (n = 19)[c]		
(m/sec)	4 yrs; 2.0 (n = 19)		
	5 yrs; 2.4 (n = 23)		
	6 yrs; 2.8 (n = 22)		
	7 yrs; 2.8 (n = 19)		

[a] Source: Roy, Youm & Roberts (1973).
[b] Source: Horita, Kitamura & Kohno (1991).
[c] Source: Philips, Clark & Peterson (1985).
[d] Projection angle is defined as the angle formed by a horizontal axis and the resultant velocity vector at the center of mass of the body.

Table 3
Mean Values of Whole Body Kinetic
Variables Studied in the Standing Long Jump

Variable	Value	Variable	Value
Peak Force (times body weight)		Power	
vertical	20 yrs; 2.16[a] 6 yrs; 2.08	vertical (ft-lb/sec)	7 yrs; 494.6 (n = 15)[b] 10 yrs; 603.4 (n = 15) 13 yrs; 960.6 (n = 20) 16 yrs; 1428.4 (n = 5)
horizontal	20 yrs; 1.29[a] 6 yrs; 0.83		
Total Work		horizontal (ft-lb/sec)	7 yrs; 241.0 (n = 15) 10 yrs; 481.0 (n = 15) 13 yrs; 815.0 (n = 20) 16 yrs; 1258.0 (n = 5)
total (J)	20 yrs; 1407 (n = 12)[a] 6 yrs; 211 (n = 8)		

[a] Source: Horita, Kitamura & Kohno (1991).
[b] Source: Roy, Youm & Roberts (1973).

component tended to remain constant from seven through 16 years of age. Acceleration data suggested that no trend exists in the vertical component of acceleration. Studies by Davies and Rennie (1968) and Payne et al. (1968) also suggest that the vertical acceleration tends to remain constant in jumping activities; mass, therefore, would be the only factor which differentiates between age groups. Conclusions drawn by Roy et al. (1973) suggested that the increase in force and power components from one age group to another could be attributed to the increase in mass as the acceleration tended to remain constant. Therefore, they concluded that the neuromuscular and temporal patterns in terms of muscle action potential are well established by seven years of age in the standing long jump.

The most rapid development in the standing long jump has been reported to be between three and seven years of age. Age-related changes in mechanical parameters of jumping during this period have been investigated. Philips et al. (1985) explored changes in takeoff parameters using film records of 102 children from 5 age groups (3, 4, 5, 6, and 7 yrs). Data was submitted to a multivariate analysis of variance on 15 variables of interest.

The shoulder angle was found to evidence increasing flexion with increasing age. Significant differences ($p < .01$) were found in all segmental angles of inclination (relative to horizontal), but the differences were confined primarily to contrasts between the three year olds and the other age groups. There was a tendency for the center of mass of the body to be located horizontally farther from the toes (in the direction of the jump) as age increased. A greater lean toward the jumping direction with increasing age was also evidenced.

Identification of mechanical variables

The developmental staging approach introduced by Seefeldt and Haubenstricker (1983) in which they "... began viewing movement as a biomechanical phenomenon, through which joint actions could be identified, ordered and classified" (p. 311) demonstrated that motor skills may be reduced to a quantifiable form for analysis. However, the qualitative methods they used to describe the staging criterion did not employ a quantifiable approach. This limited their ability to test the true nature of their staging sequences. Hay (1982) expanded on the suggestions of quantifiable analysis as the basis for evaluating motor skills with the introduction of his deterministic model of human movement. This provided a framework for identifying least common denominators in a motor skill, in terms of the kinematic and kinetic variables that define a performance (e.g., distance in the standing long jump). However, Hay used a solely kinematic description with his deterministic model to define the standing long jump (1988, p. 254). To define a performance of the standing long jump, Hay determined that it was necessary to subdivide the performance into four phases: (1) takeoff distance (the horizontal distance from the center of gravity of the body to the point on the toes closest to the takeoff mark), (2) flight distance (the horizontal distance traveled by the center of gravity of the body from takeoff to landing), (3) landing distance (the horizontal distance from the center of gravity of the body to the point on the heels closest to the takeoff mark), and (4) fall back distance (the horizontal distance from the point on the heels closest to the takeoff mark to the part of the body that falls behind the heels closest to the takeoff mark) - zero for a preferred landing.

Multidimensional Scaling

Multidimensional scaling (MDS) refers to a class of techniques that uses proximities among variables as input (Kruskal & Wish, 1978). The proximity measure is a number which indicates how similar or dissimilar two variables are, or are perceived to be. The output of these techniques is a spatial representation of a geometric configuration of points. The configuration represents the latent structure (relationships between variables) of the data points which is often the purpose of using a geometric representation. The resulting map plots the data points in a scaled manner based upon the degree of similarity (i.e., the greater the similarity, the closer the points in a spatial configuration). The power of MDS lies in its ability to generate a spatial diagram that may be interpreted to yield useful insights. The ability of the investigator to interpret the resulting configuration(s) is important in deriving meaning from these relationships. MDS results in plots of the variables in a configuration representative of the relationship between variables transformed into Euclidian distances. The constructs that determine these relationships must be interpreted by the investigator based upon his/her knowledge of the variables. A priori knowledge of an underlying structure, or even a hypothesis as to possible structure, becomes a valuable tool to the researcher using this class of techniques.

Notation used in multidimensional scaling has been well defined by Kruskal and Wish (1978). The computational formulae that describe MDS are written in matrix notation. To indicate a collection of objects, i is used to denote the first subscript, and j to denote the second. The proximity or data value connecting object i with object j is denoted by ∂_{ij} (read delta sub ij). The collection of values ∂_{ij} are arranged in a matrix denoted by Δ. Thus, for a collection of i = 3 objects:

$$\Delta = \begin{vmatrix} \partial_{11} & \partial_{12} & \partial_{13} \\ \partial_{21} & \partial_{22} & \partial_{23} \\ \partial_{31} & \partial_{32} & \partial_{33} \end{vmatrix}.$$

Central to the theory of MDS is the interpretation of geometric distance between any two variables. Kruskal and Wish (1978) indicated the distance between any two points, x_i and x_j, by

$$d(x_i, x_j) = \text{distance from } x_i \text{ to } x_j, \qquad (2\text{-}1)$$

which may be simplified to

$$d_{ij} = d(x_i, x_j). \qquad (2\text{-}2)$$

The distance between any two points x_i and x_j is taken as the ordinary Euclidian distance (which may be measured with any standard linear measuring device). By the Pythagorean formula, this distance may be denoted as the square root of

$$d_{ij} = [(x_{i1} - x_{j1})^2 + \ldots.. + (x_{ir} - x_{jr})^2], \qquad (2\text{-}3)$$

which may be rewritten in sigma notation as the square root of

$$d_{ij} = [\Sigma (x_{ir} - x_{jr})^2]. \qquad (2\text{-}4)$$

Arranged in matrix form, for example with i = 3, the notation becomes,

$$\begin{vmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{vmatrix}.$$

The distances within this matrix are the proximity measures being used to show the degree of similarity (or dissimilarity) between any two corresponding objects. Plotting these similarity measures on a scattergram to gain a better perspective of the nature of the data is common in statistics. Representing the dimension of one object along the horizontal axis and the dimension of another along the vertical, Kruskal and Wish (1978) stated that a linearly decreasing relationship similar to that depicted in Figure 4 is representative of a good fit of the data. To express this relationship in a formula, the standard equation for a straight line is representative, with the distance that each individual value varies from the line of best fit being a function of the similarity measure. Thus,

$$d = a + b\partial, \qquad (2\text{-}5)$$

where the values for a and b describe the relationship between the two independent measures. When expressing this relationship where the straight line goes through the origin of the graph,

$$d = b\partial\,. \qquad (2\text{-}6)$$

There are several numerical methods that approximate the values for ∂ and d. However, it must be kept in mind that the greater the variability in the data (i.e., the more dispersion in the scattergram) the more difficult it will be to achieve a good estimate of the parameters ∂ and d.

The problem addressed in MDS thus becomes one of finding the best fit of such a function (3-7) to the data. It is important to remember that many different types of functions

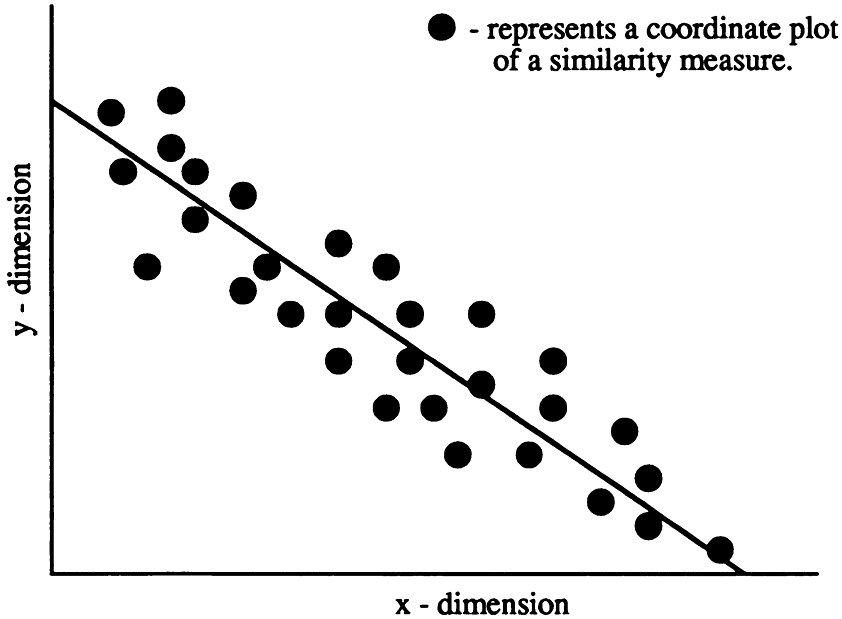

Figure 4. Linearly decreasing pattern associated with similarity measures between variables.

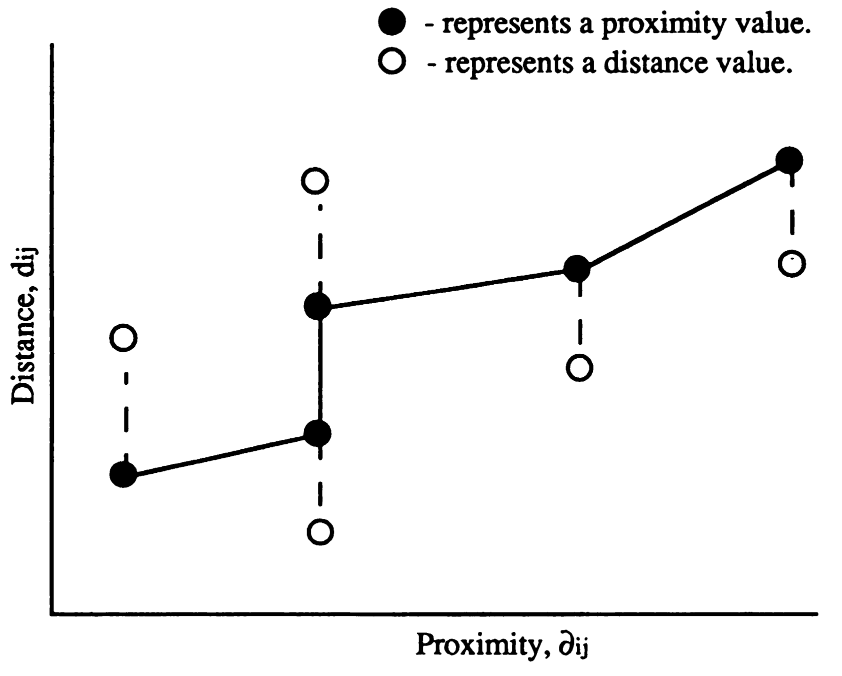

Figure 5. Differences between proximity and distance values used in the calculation of a stress function.

exist that may produce the best fit. For example, in a relatively linear relationship such as the one discussed previously (see Figure 4), the equation of a line may form the best fit of the data. However, if the data were to show curves in the geometric representation given in the scattergram, a polynomial equation may be more appropriate. The problem of finding the equation of best fit was addressed by Kruskal and Wish (1978) in terms of defining an objective function.

The objective function will yield a single number which will indicate the degree to which the data fit the configuration generated. Thus, if an objective function is defined as

$$f(\partial_{ij}) = d_{ij}, \qquad (2\text{-}7)$$

where f represents some specified function type, an objective function can be defined as

$$f(\partial_{ij}) - d_{ij}. \qquad (2\text{-}8)$$

This may be literally interpreted as the distance between the proximity measure ∂_{ij} and distance d_{ij} (see Figure 5). The common mathematical procedure for determining the size of these differences is to square this value (all values become positive) and to sum the squared differences for all proximity values. Thus the size of the difference becomes

$$\sum_i \sum_j [f(\partial_{ij}) - d_{ij}]^2. \qquad (2\text{-}9)$$

In order to make this value interpretable, it is divided by a scaling factor. The scaling factor used by Kruskal and Wish (1978) is,

$$\sum_i \sum_j d_{ij}^2. \qquad (2\text{-}10)$$

The final step is to take the square root of the function which results in an objective function called the "f-stress". The f-stress is defined as the square root of:

$$\frac{\sum_i \sum_j [f\partial_{ij}) - d_{ij})^2}{\text{scaling factor.}} \qquad (2\text{-}11)$$

The larger the f-stress the poorer the fit of the configuration and function jointly. An f-stress of zero would indicate that ∂_{ij} is perfectly related to d_{ij} by the function of the desired type.

Summary

The purpose of this study was to investigate the staging sequence of a fundamental motor skill (standing long jump). The sequence under investigation (Seefeldt et al., 1972) is one of several staging sequences that have been proposed for the standing long jump. Although these sequences may have differences in the values of their parameters, they all have one common characteristic. All of the sequences are based upon measurable biomechanical parameters. This allows the staging sequences to be described quantitatively.

The mechanical variables associated with staging sequences have a maturational component. In addition, it is a basic assumption within a sequence that progression from one stage to a higher stage is associated with a higher level of performance in the objective of the activity. Thus, for a motor activity, a higher stage would be associated with better use of the mechanical parameters that produce the performance. These postulates, as to the progression of motor activities, have lead to the following research questions.

Question 1. Are the stages of the standing long jump related to the maturational characteristics of age?

Question 2. Are the stages of the standing long jump related to body composition (percent body fat) and size (segmental masses)?

Question 3. Does the objective of the standing long jump (distance) differentiate between the developmental stages of the performance?

Question 4. Are the stages of the standing long jump differentiable by body orientation at takeoff and landing?

Question 5. Are the stages of the standing long jump differentiable by the contributions of the individual body segments (acceleration, force)?

Question 6. Can stage theory as a construct be validated using multidimensional scaling?

The first five research questions address the individual differences between stages as evidenced by the mechanical variables that contribute to the performance. Question six addresses the validity of the overall theory by asking the question; "Can stage theory be validated empirically by investigating the ordering of its developmental progression towards mature performance?"

Chapter III

METHODS AND MATERIALS

The conduct of this investigation was divided into two main categories. These categories are (1) a comparison of stages of the standing long jump using multivariate and univariate statistics and (2) an investigation of the staging sequence of the standing long jump as a construct using multidimensional scaling. A brief review of the procedures used to identify the variables for study precedes these sections. Following a description of these categories, including data collection tools and methods, specific statistical techniques will be discussed in detail. This discussion will include a prestudy designed as an example of the use of multidimensional scaling.

Identification of Variables

The purpose of this investigation was to study the kinematic and kinetic variables associated with the staging sequence of a fundamental motor skill (standing long jump). The specific staging sequence chosen was that presented by Seefeldt et al. (1972). To this end, the kinematic, kinetic, and anthropometric variables associated with the performance of the standing long jump were measured, reduced, and analyzed. The following sections will detail the procedures used in completing this task.

Mechanical variables

Three specific events during the performance of the standing long jump were identified. The first event was defined by the initiation of movement by the performer. The first initiation of movement was identified by the point on the force-time recording of first force application or unloading. Children were instructed to assume a standard fundamental standing position (Luttgens & Wells, 1989, p. 24) in order to assure a distinct marking of this movement. The configuration of body segments at this point is important as it represents the starting point for the preparatory movements of the skill.

The second event was the takeoff point for the performance. For this event, the kinematic and kinetic variables must be defined using different criteria. The point of takeoff was taken as a distinct event for assessing kinematic parameters. The point of takeoff was assessed at the unloading mark on the force-time curve. The kinetic parameters were defined from the initiation of movement in preparation for the jump to the point of takeoff.

The third event was the moment of first contact with the landing surface. This event was identified using cinematographic data. The specific event(s) at which variables were measured depended upon the usefulness of the variable during any event. For example, a force reading taken from a force platform, used to record takeoff forces, would be zero during the landing phase. This is due to a lack of contact with the platform at this phase of the performance.

Expanding on Hay's (1988) deterministic model, this author has defined the performance of the standing long jump in terms of both kinematic and kinetic variables (see Figure 6). The lowest level of any of the three components (takeoff, flight, landing) shown in Figure 6 thus becomes a variable of study (indicated by bold boxes). For example, the takeoff component of the jump can be completely described in biomechanical terms by the horizontal distance from the center of mass of the body to the point on the toes closest to the takeoff line (see Figure 7). The deterministic model, then, provides the kinematic and kinetic variables to be measured by showing that all other variables are simply a function of these lowest common denominators of mechanical parameters.

To determine individual force contributions of body segments to the performance, the mass of each segment is necessary, these contributions are calculated using the equations,

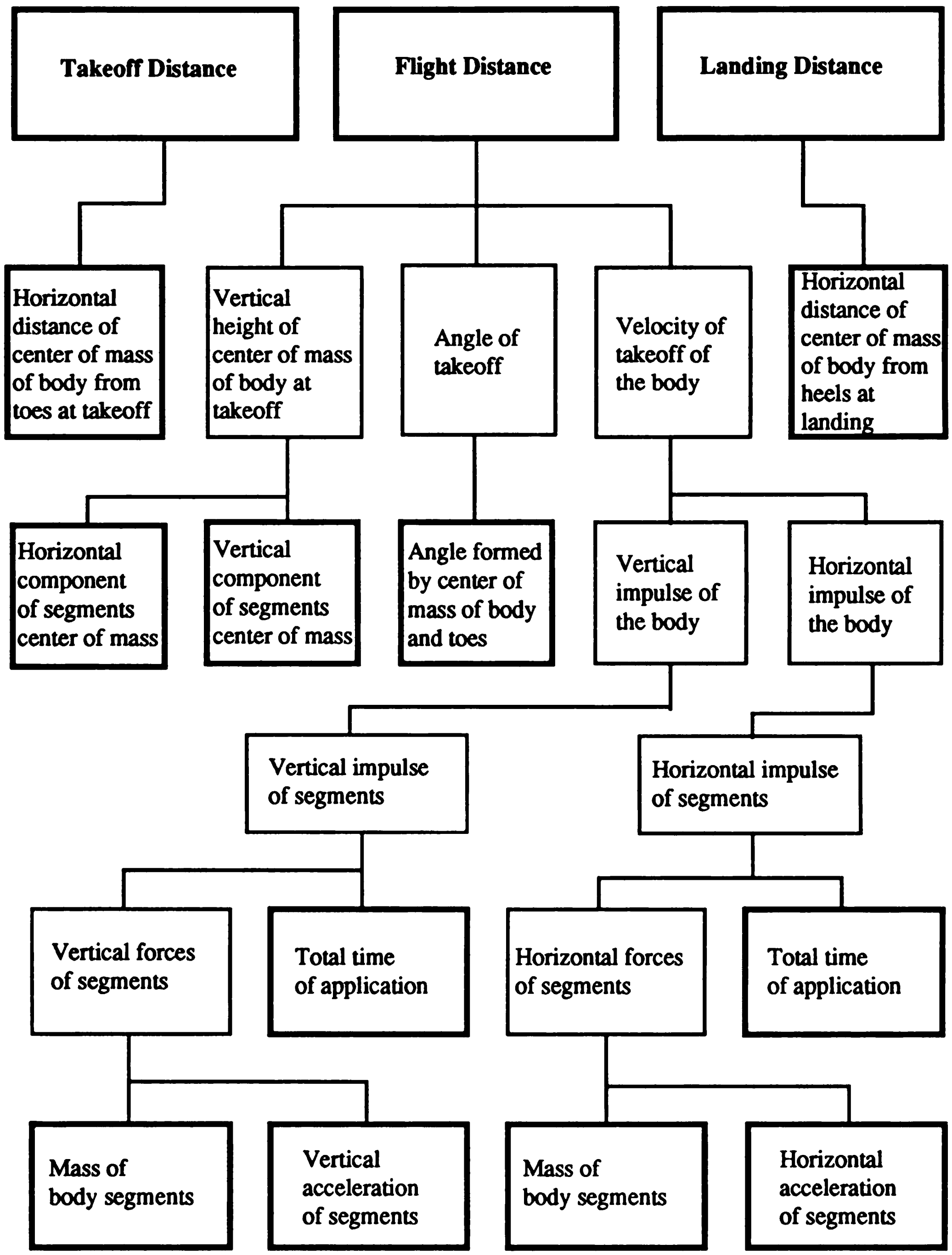

Figure 6. Deterministic model of mechanical contributions to distance in the standing long jump.

a - Distance loss from starting mark
b - Angle of takeoff
c - Takeoff gain
d - Landing gain

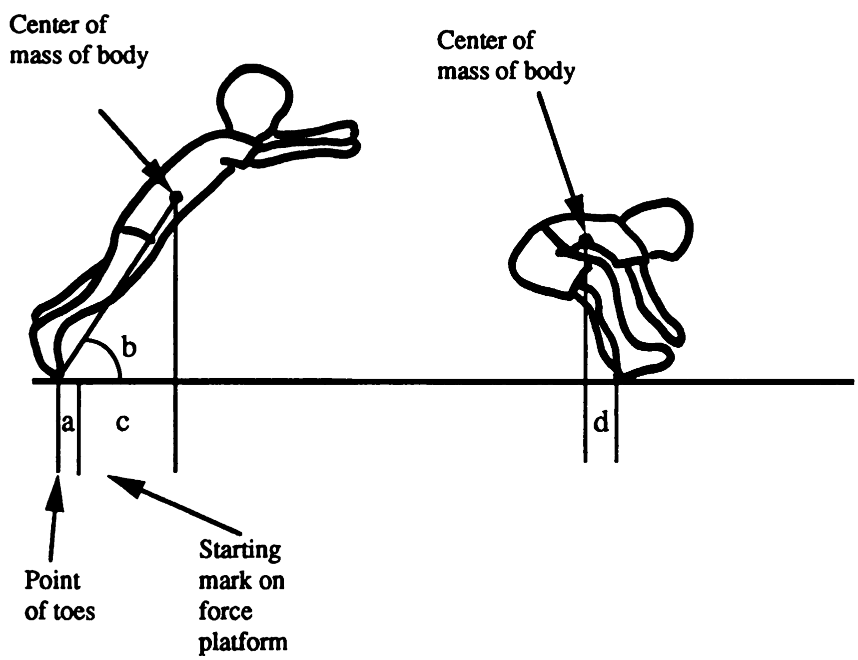

Figure 7. Contributions to distance in the standing long jump.

$$F_{ix} = m_i a_{ix},$$
$$F_{iy} = m_i a_{iy}, \quad (3\text{-}1)$$

where i = ith body segment, x = anterior-posterior direction, y = vertical direction. The mass of body segments were calculated as a proportion of total body mass (weight) using regression equations reported by Jensen (1986).

Strength variables

A measure of dynamic leg strength was recorded by having the subjects perform a maximal jump for height from a force platform. Peak vertical force was recorded for the jump as a measure of jumping strength. In order to minimize the effects of form on the force produced, the subjects performed the jump with their hands held at their waist during the duration of the jump.

Subjects

A prescreening of potential subjects was conducted in order to identify those who exhibit "classic" features of a given stage (stages proposed by Seefeldt et al., 1972). Screening took place within the Motor Performance Study (MPS) and Early Childhood Project (ECP) at Michigan State University. The stages correspond to an approximate age range of 2 to 7 years. The subjects chosen for participation in the study were all between the ages of 4 and 7 years. This represented a homogeneous group within the ages identified as those in which the progression between stages occurs. Qualitative assessment of stage of development for the standing long jump was conducted using direct visual evaluation by a motor development "expert" (a faculty member with expertise in motor development) and videotaping for subsequent verification. From the potential subjects identified as representing the four qualitative stages, forty healthy subjects were selected. This

procedure provided a total sample of thirty-three subjects. The seven subjects not represented were lost either due to unwillingness to participate or unusable data resulting from equipment failure.

Data Collection

Anthropometric measurement

Selected anthropometric measurements were taken for each subject prior to filming. Subjects were weighed on a weight-beam scale to the nearest one-tenth kilogram. The subjects were shown each of the measurement devices (i.e., bow caliper, short anthropometer, long anthropometer, steel tape, and skinfold caliper) and told that the devices will be used to measure "how big you are." Before each measurement, the children were given a demonstration of how they should stand or sit for the measure. Distance measurements on the right side of the subjects were taken to the nearest millimeter following the procedures outlined by Lohman et al. (1988). A detailed list of the anthropometric measurements taken and the data collection form can be found in Appendix A.

Cinematographic and force platform procedures

The starting position of the feet for the performance of the standing long jump was marked on the surface of an AMTI force platform. Subjects were instructed to place their toes as close to this starting mark as possible. A demonstration of the standing long jump was provided for each subject, followed by an opportunity for practice attempts. Prior to actual data collection, each subject was given an opportunity to listen to the camera sounds while a reference measure meter stick was filmed. The meter stick was used as a linear procedure provided a total sample of thirty-three subjects. The seven subjects not represented were lost either due to unwillingness to participate or unusable data resulting from equipment failure.

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conversion factor for subsequent planer analysis. The standing long jump of each subject was then filmed while force recordings were simultaneously obtained. Two trials were recorded. Additional trials were provided if a subject failed to jump in the desired direction, or a fall back occurred. The trial selected for analysis was the one that demonstrated the best overall performance (greatest distance) with no fall back.

A 16mm LOCAM high-speed camera equipped with F 12-1200 mm zoom lens was used for filming. The camera was mounted on a tripod and positioned to the right side of the subject. The optical axis of the lens of the camera was perpendicular to the activity plane of the performance (see Figure 8). A film rate of 100 frames per second with a shutter angle of 120 degrees was used. This created an exposure time of 1/300th second for each image. Kodak 125 ASA color film was used. A timing light box capable of measuring up to 1/1000th second and a plumb line, to precisely measure frame rate and orientation, respectively, were located in the field of view. The filming area was illuminated by portable and permanantly mounted tungsten-halogen lights. A gray CBS curtain provided a neutral background for filming.

Body segment markers were placed on the subjects to aid in the location of anatomical sites during the film digitizing process. The following sites on the right side of the body were marked: joint centers of the ankle, knee, hip (greater trochanter), shoulder, elbow, and wrist. Colored adhesive 1/2 inch circular disks were fixed to each site.

Data Reduction

Cinematographic data was reduced using a digitizing process prior to statistical analysis. The film was projected onto a drafting table by a Van Guard Motion Analyzer. A Science Accessories sonic digitizer was used to convert points on the projected film image into Cartesian coordinates for further analysis. Data was reduced and stored using the DATAQS computer program developed at Michigan State University. Data was then

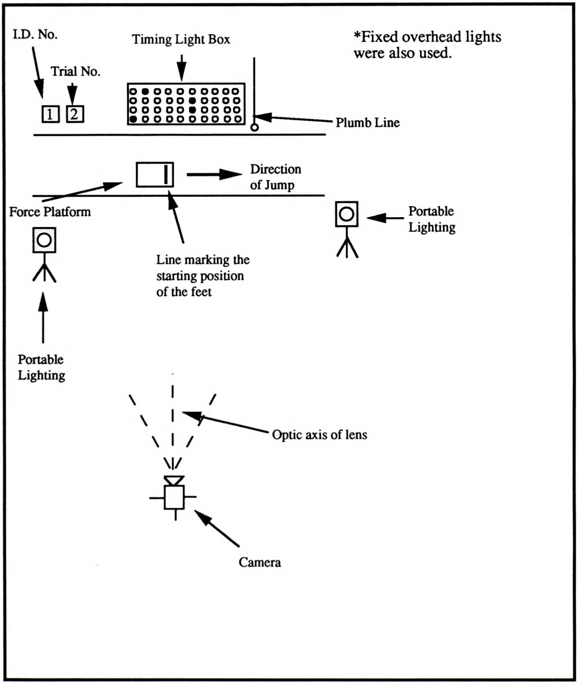


Figure 8. Data collection setting.

uploaded to an IBM 3090 mainframe computer for analysis. Kinematic and kinetic data was generated using specially developed software including a double-pass Butterworth filter for data smoothing.

Force platform recordings were obtained and stored by an IBM 9000 laboratory microcomputer with software developed at The Center for the Study of Human Performance (CSHP) at Michigan State University. Resulting force-time impulse curves were generated for interpretation.

Force-time recordings and cinematographic data were synchronized by matching an electronic signal generated from the timing lights with the film record of this event. Initiation of movement by the subjects as evidenced on the film record was matched with the first recording of change in force. Final unloading from the takeoff surface as indicated by the force curve was matched with the first frame of film showing loss of contact with the takeoff surface.

Data on all variables were collected in computer record format (i. e., a continuous string variable) with variable identifiers for computer analysis. Inter-rater reliability for the digitizing process resulted in a correlation of 0.92 between trials.

Prestudy using multidimensional scaling

Multidimensional scaling is a relatively new statistical technique (Torgerson, 1958) that has not yet been applied to the study of human movement. For this reason, researchers of physical activity have little or no knowledge of the potential of MDS as a tool for investigating constructs in physical education. A prestudy was conducted to demonstrate the use of multidimensional scaling and explain its potential use in determining the constructs that underlie the development of motor skills. From an existing database, 17,960 total measurements of eleven anthropometric variables taken two times a year as part of a longitudinal study were selected for trial application of MDS. An intercorrelational matrix

of the eleven measures was calculated using the PEARSON subroutine (SPSS-X, Mainframe version, 1988) (see Table 4). The correlation coefficients may be viewed as the proximity measures between variables. The lower-diagonal matrix thus becomes the input for the MDS package KYST (Kruskal-Young-Shepard-Torgerson, 1983). The resulting f-stress values were compared for one to three dimensions. A stress value of 0.009 for the two-dimensional configuration was selected for further interpretation. The coordinates plotted by the computer program are not generally interpretable by direct examination. Kruskal and Wish (1978) explained,

> The coordinates printed out and plotted by the computer are not generally susceptible to direct interpretation. To understand why this is so, recall that they represent the positions of the points along the coordinate axes, that is, the projections of points on the axes. Now it is permissible to rotate the configuration, and if we do so these projections change quite drastically (p. 34).

Plotting the two-dimensional coordinates shown in Figure 9 A for the eleven anthropometric variables resulted in the configuration given in Figure 9 B. An initial subjective evaluation of this configuration produced an interpretation of the axes yielding a dimension representative of a dermal tissue continuum (endomorphic to the ectomorphic) for dimension 1. Dimension 2 was interpreted as a proximal to distal body location axes (axial to appendicular).

Linear regression for dimensional interpretation

The most widely used and easiest to understand method to interpret the axes is based upon linear regression. The first step is generally a subjective interpretation of the configuration. This yields some variable which may be related to the position of the variables of interest. To investigate this possible relationship, a linear multiple regression may be performed using this variable as the dependent variable and the coordinates of the configuration as the independent variables. This procedure seeks to gain some weighted combination of the coordinates that "explains" the related variable as well as possible. The

Table 4
Intercorrelation Matrix for Eleven Anthropometric Measures

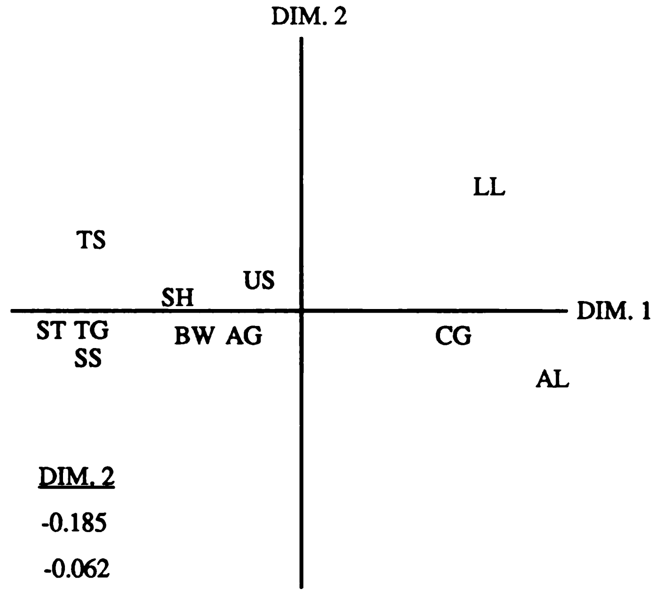
	BW	CG	LL	SH	ST	SS	TG	TS
Body Weight (BW)	1.000							
Calf Girth (CG)	.9566	1.000						
Lower Arm Length (LL)	.9308	.9070	1.000					
Sitting Height (SH)	.9442	.8767	.9229	1.000				
Standing Height (ST)	.8896	.9125	.9839	.9397	1.000			
Subscap. Skinfold (SS)	.5614	.5653	.3845	.3919	.3805	1.000		
Thigh Girth (TG)	.9492	.9650	.8891	.8767	.8948	.6224	1.000	
Triceps Skinfold (TS)	.2757	.3412	.1363	.1508	.1354	.6899	.4088	1.000
Umbilicus Skinfold (US)	.5551	.5751	.4008	.4002	.3949	.8421	.6314	.7104
Upper Arm Girth (AG)	.9413	.9374	.8508	.8211	.8485	.6399	.9487	.4227
Upper Arm Length (AL)	.9258	.9051	.9815	.9226	.9846	.3906	.8914	.1529

	US	AG	AL
Umbilicus Skinfold (US)	1.000		
Upper Arm Girth (AG)	.6517	1.000	
Upper Arm Length (AL)	.4065	.8445	1.000

measure used for this interpretation is the multiple correlation coefficient.

For the two dimensional configuration, the i-th item has coordinates (x_{i1}, x_{i2}). If the variable has value v_i for the i-th item, this means the procedure is looking for coefficients a, b_1, b_2 such that the function values

$$a + b_1 x_{i1} + b_2 x_{i2} \qquad (3\text{-}2)$$



(B)

(A)

STIMULI	DIM. 1	DIM. 2
Body Weight (BW)	-0.318	-0.185
Calf Girth (CG)	1.313	-0.062
Lower Arm Length (LL)	1.257	0.644
Sitting Height (SH)	-0.498	0.048
Standing Height (ST)	-0.840	-0.079
Subscapular Skinfold (SS)	-0.835	-0.101
Thigh Girth (TG)	-0.835	-0.088
Triceps Skinfold (TS)	-0.820	-0.263
Umbilicus Skinfold (US)	-0.139	0.129
Upper Arm Girth (AG)	-0.221	-0.161
Upper Arm Length (AL)	1.936	-0.408

(C)

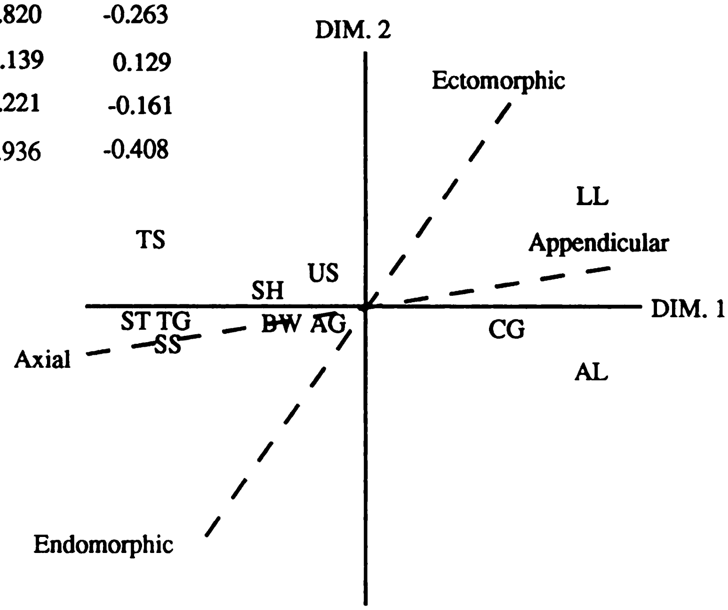


Figure 9. Stimulus coordinates from a two-dimensional KYST2 analysis of the anthropometric data are listed in (A) and plotted in (B). The dashed lines in (C) were drawn to indicate the subjective interpretations of the dimensions.

agree with the values v_i as well as possible. The least squares linear regression method, that is by far the most common method (Kruskal & Wish, 1978, p.36) seeks to choose the coefficients which minimize

$$\sum [v_i - (a + \sum_{r=1}^{2} b_r x_{ir})]^2. \qquad (3\text{-}3)$$

There are a number of commercially available programs to perform this procedure.

The dependent variables chosen for this study to demonstrate the use of linear multiple regression for axes interpretation are the previous subjective interpretations. The same eleven anthropometric measures used to generate the distance configuration were rated by thirteen students in a graduate course in motor development on a 0 to 7 Likert scale for each of the four bipolar axes scales (see Figure 10). Students were provided with a description of each of the measures as well as the bipolar descriptors prior to completing the questionnaire. The first step toward the interpretation of dimensions was to average subjects' ratings of the anthropometric measures on each of the four bipolar scales The last two columns of Table 5 show the mean ratings of the measures on the two scales. The next step was to use the multiple regression procedure, REGRESSION (SPSS-X, Mainframe version, 1988), to regress the mean ratings of anthropometric measures over the two dimensions listed in Table 5.

The first two columns of Table 6 list the beta weights corresponding to each multiple correlation shown in the third column. The fourth and fifth columns list the optimum regression weights for the beta coefficients. These regression weights are the direction cosines. The cosines are regression coefficients normalized so that their sum of squares equals 1.00 for every scale. For the two-dimensional case, normalizing coefficients β_1 and β_2 (regression coefficients for the two independent dimensions) is solved:

Directions: For each of the anthropometric measures listed below, circle the appropriate number to the right of the statement to indicate the degree to which you feel the measure is representative of the bipolar descriptors at either end of the rating scale. There are no right or wrong answers.

	Appendicular							**Axial**
Body Weight	0	1	2	3	4	5	6	7
Calf Girth	0	1	2	3	4	5	6	7
Lower Arm Length	0	1	2	3	4	5	6	7
Sitting Height	0	1	2	3	4	5	6	7
Standing Height	0	1	2	3	4	5	6	7
Subscapular. Skinfold	0	1	2	3	4	5	6	7
Thigh Girth	0	1	2	3	4	5	6	7
Triceps Skinfold	0	1	2	3	4	5	6	7
Umbilicus Skinfold	0	1	2	3	4	5	6	7
Upper Arm Girth	0	1	2	3	4	5	6	7
Upper Arm Length	0	1	2	3	4	5	6	7

	Ectomorphic							**Endomorphic**
Body Weight	0	1	2	3	4	5	6	7
Calf Girth	0	1	2	3	4	5	6	7
Lower Arm Length	0	1	2	3	4	5	6	7
Sitting Height	0	1	2	3	4	5	6	7
Standing Height	0	1	2	3	4	5	6	7
Subscapular Skinfold	0	1	2	3	4	5	6	7
Thigh Girth	0	1	2	3	4	5	6	7
Triceps Skinfold	0	1	2	3	4	5	6	7
Umbilicus Skinfold	0	1	2	3	4	5	6	7
Upper Arm Girth	0	1	2	3	4	5	6	7
Upper Arm Length	0	1	2	3	4	5	6	7

Figure 10. Likert scale questionnaire for axes interpretation.

Table 5
Two-Dimensional KYST2 Solution for Eleven Anthropometric Measures (shown in the first two columns) and Mean Ratings of These Measures On The Two Bipolar Scales

Anthropometric Measure	Dim. 1	Dim. 2	Axial-Appen.	Ecto.-Endo.
Body Weight	-0.318	-0.185	5.15	4.92
Calf Girth	1.313	-0.062	2.23	4.15
Lower Arm Length	1.257	0.644	1.23	1.69
Sitting Height	-0.498	0.048	5.92	2.38
Standing Height	-0.840	-0.079	4.31	1.69
Subscap. Skinfold	-0.835	-0.101	5.23	4.62
Thigh Girth	-0.835	-0.088	2.85	4.75
Triceps Skinfold	-0.820	-0.263	1.92	4.15
Umbilicus Skinfold	-0.139	0.129	5.46	5.23
Upper Arm Girth	-0.221	-0.161	2.15	4.31
Upper Arm Length	1.936	-0.408	1.77	2.00

Table 6
Multiple Regression of Bipolar Scale Ratings on Dimensions of Relatedness Among Anthropometric Measurements

Positive Poles of Rating Scales	ß1	ß2	Multiple Correlation	Regression Weights (Direction Cosines) Dim. 1	Dim. 2
1. Axial-Appen.	-.565	.052	0.748	0.996	0.091
2. Ectomor.-Endo.	-.369	-.209	0.672	0.870	0.494

$$c\beta_1^2 + c\beta_2^2 = 1. \tag{3-4}$$

Gathering similar coefficients,

$$c(\beta_1^2 + \beta_2^2) = 1, \tag{3-5}$$

and solving for c yields

$$c = 1 / (\beta_1^2 + \beta_2^2). \tag{3-6}$$

Thus, the normalized regression weights are found by multiplying the constant, c, times the individual beta weights and taking the square root. For example, when weights of 0.996 and 0.091 are given to dimensions 1 and 2, respectively, the correlation between the resulting composite and mean ratings on the first scale is 0.748.

Kruskal and Wish (1978) list two conditions necessary for a rating scale to provide a satisfactory interpretation of a dimension: (1) the multiple correlation coefficient for the given scale must be sufficiently high (this would indicate that the scale is well fitted by the coordinates of the configuration) and (2) the scale must have a sufficiently high regression weight on the dimension. This would indicate that the angle between the dimension and the direction of the associated scale is small. A multiple correlation of 0.90 or greater is recommended for a good interpretation of a dimension. The minimal requirement suggested by Kruskal & Wish (1978) is a multiple correlation statistically significant at the 0.01 level.

Two dimensions for this trial application of MDS were readily interpretable. A multiple correlation of 0.996 for dimension 1 of the "axial-appendicular" axes corresponds to an angle of 5 degrees (cosine 5 degrees = 0.996). The multiple correlation of 0.870 for the first dimension of the "endomorphic-ectomorphic" axes may by interpreted as an angle of 30 degrees (cosine 30 degrees = 0.870). Using the previous subjective interpretations as a gu

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a guide, the configuration shown in Figure 11 was constructed.

Two distinct clusterings of variables are evident in the configuration. On the left side (axial-endomorphic), the skinfold measures, axial limbs, and total body assessments are found. For example, triceps and subscapular skinfolds are located to the far left. In addition, body weight and standing height, the two total body measures are located to the left side.

The right side of the configuration (appendicular-ectomorphic) contains the axial limb measures. Lower arm length, arm length, and calf girth are located on this side.

The KYST2 program was clearly able to give a pictorial representation of the relationships between these variables based only on the correlation between each individual measure. The correctness of fit of the dimensions, as they have been represented, depends upon the accuracy of the investigator in selecting the appropriate scales. Although this interpretation did not meet the statistical criterion established by Kruskal and Wish (1978) (a multiple correlation of 0.90 or greater), it served as a useful example of the capability of multidimensional scaling to aid in the interpretation of constructs underlying the relationships between variables.

Summary

This chapter outlined the procedures used to identify and collect the data used in this study. A deterministic model was developed to identify the mechanical variables that contribute to the performance of the standing long jump. Potential subjects were screened for qualitiative stage of the standing long jump and verified using videotape. Anthropometic and cinematographic procedures were outlined.

A prestudy conducted in order to demonstate the potential use of multidimensional scaling was presented. This study used data from an existing database to show the configuration that is generated using the KYST2 multidimenional scaling program. Linear regression

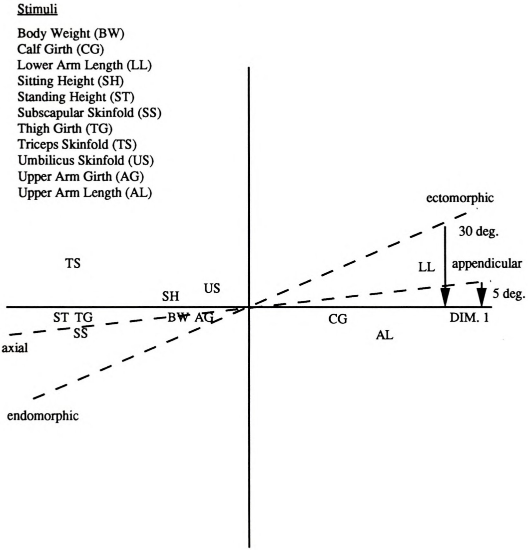

Figure 11. Dimensional interpretation of KYST2 configuration using linear multiple regression.

regression used to interpret the dimensions generated was shown.

The configuration generated by the KYST2 program was found to produce a pictorial of the relationships between the input variables that was readily interpretable. Although this interpretation did not stand up to statistical guidelines, it was found to be a useful tool in demonstrating the potential usefulness of multidimenional scaling in interpreting the relationships between variables.

Chapter IV

RESULTS

This chapter consists of four main sections. Descriptions of the subjects and their mass distribution characteristics are included in the first section. Kinematic and kinetic results are included in sections two and three. Finally, the results and interpretation of the multidimensional scaling are included in section four.

Subject Description

There were thirty-three subjects (25 males and 8 females) included in the final analysis. Informed consent forms (see Appendix B) were signed by the children's parents. Seven of the original forty subjects identified were eliminated either due to their unwillingness to participate or unusable kinetic data resulting from equipment failure. Table 7 presents the means and standard deviations of the descriptive variables by qualitative stage of standing long jump ability. Percent body fat was calculated from the regression equations given by Mukherhee and Roche (1984).

A multivariate analysis of variance (MANOVA) was performed on each of the tables presented in chapter IV to control for the overall alpha level. A full factorial between-subjects design was selected. For Table 7, a 3 (subject descriptor) X 4 (stage) MANOVA was conducted. A non-significant Hotelling's value ($F[9, 77] = 1.23$, $p < .289$) indicated that no further univariate analyses were justified.

<u>Mass of subjects</u>

Segmental masses were calculated from the anthropometric measures using regression equations presented by Jensen (1986). Symmetry between corresponding

Table 7
Subject Description

Variable		Stage 1 (n=5)	Stage 2 (n=12)	Stage 3 (n=11)	Stage 4 (n=5)
Age (mths)	M	72.00	72.17	75.18	83.60
	SD	±12.57	±9.81	±10.24	±5.86
Weight (kg)	M	24.65	21.01	22.07	21.34
	SD	±6.50	±3.63	±3.22	±4.09
% Body Fat	M	23.72	22.72	22.98	18.87
	SD	±3.95	±4.34	±4.43	±1.95

bilateral body segments (e.g., right and left foot) was assumed in calculating segmental masses. Means and standard deviations of the mass characteristics of the subjects, by stage of standing long jump, are given in Table 8. An 8 (mass characteristics) X 4 (stage) MANOVA resulted in a non-significant Hotelling's value ($F[24, 62] = 1.25$, $p < .239$).

Kinematics

Positional characteristics

The total horizontal distance jumped was calculated by taking the difference between the position of the toes at takeoff and the position of the heels at landing (refer to Figure 5, chapter III). Takeoff gain was calculated as the horizontal difference between the position of the toes and the center of mass of the subject at takeoff. The center of mass of the subject was generated by the computer program for kinematic and kinetic analysis. Landing gain was calculated as the horizontal difference between the heels and the center of mass at landing. The angle of takeoff was calculated as the arctangent of the vertical distance from the floor to the center of mass of the body divided by the takeoff gain.

Table 8
Body Subject Mass Characteristics

Variable (kg)		Stage 1 (n=5)	Stage 2 (n=12)	Stage 3 (n=11)	Stage 4 (n=5)
Total mass	M	24.65	21.01	22.07	21.34
	SD	±6.50	±3.63	±3.22	±4.09
Mass of feet	M	0.93	0.82	0.86	0.84
	SD	±0.30	±0.16	±0.13	±0.16
Mass of shank	M	2.15	1.88	1.99	1.97
	SD	±0.71	±0.35	±0.32	±0.40
Mass of thigh	M	4.13	3.62	3.86	3.67
	SD	±1.42	±0.70	±0.64	±1.09
Mass of trunk	M	10.35	8.85	9.29	8.98
	SD	±3.16	±1.52	±1.35	±1.71
Mass of arms	M	1.27	1.12	1.18	1.18
	SD	±0.43	±0.21	±0.19	±0.24
Mass of forearms	M	0.75	0.66	0.69	0.68
	SD	±0.24	±0.18	±0.10	±0.13
Mass of head	M	4.16	3.70	3.79	3.45
	SD	±1.18	±0.55	±0.51	±0.57
		Σ = 23.74	Σ = 20.65	Σ = 21.66	Σ = 20.77

Note. Column totals do not nesessarily sum to the total mass of the body due to segmental masses being calculated individually, and means calculated subsequently.

Resultant accelerations of the center of mass of each of the right side body segments were calculated for the moment of takeoff. These values were generated by finding the resultant acceleration vector from the vertical and horizontal accelerations. Means and standard deviations for distance jumped and positional characteristics are given in Table 9. Resultant accelerations of body segments at takeoff are given in Table 10.

A 11 (positional and acceleration values) X 4 (stage) MANOVA for the kinematic data produced a significant Hotelling's value ($F[12, 74] = 2.13$, $p < .006$). This indicated that subsequent univariate tests could be performed to determine which variables possessed

Table 9
Distance and Position Characteristics

Variable		Stage1 (n=5)	Stage 2 (n=12)	Stage 3 (n=11)	Stage 4 (n=5)
Distance	M	0.77[a]	0.95[a]	1.06	1.32
jumped (m)	SD	±0.25	±0.28	±0.22	±0.15
Takeoff	M	0.01	-0.01	0.07	0.07
gain (m)	SD	±0.11	±0.09	±0.10	±0.04
Landing	M	0.35[b]	0.47[b]	0.56	0.77
gain (m)	SD	±0.17	±0.16	±0.14	±0.15
Angle of	M	90.68	91.80	82.66	82.63
takeoff (deg)	SD	±12.27	±11.95	±9.56	±3.74

[a] Significantly different from Stage 4 ($p < .05$).
[b] Significantly different from Stage 4 ($p < .05$).

significant variance.

A ONE-WAY analysis of variance indicated that the variances of distance jumped ($F[3, 29] = 5.03$, $p < .006$), landing gain ($F[3, 29] = 6.65$, $p < .001$), acceleration of the thigh ($F[3, 29] = 3.91$, $p < .019$), acceleration of the trunk ($F[3, 29] = 3.10$, $p < .042$), acceleration of the arms ($F[3, 29] = 5.00$, $p < .006$), and the acceleration of the forearms ($F[3, 29] = 13.51$, $p < .000$) were all significant at the .05 level.

A Tukey post-hoc analysis was performed on these variables to determine source(s) of the variation. The Tukey post-hoc assessment indicated that there was a significant increase in the distance jumped between stages 1-2 and stage 4. Landing gain differences were also significantly different between stages 1-2 and stage 4. The accelerations of the thigh and trunk were significantly different between stage 1 and stage 4. The acceleration of the arms was also significantly different between stages 3-4 and stage 1. The greatest difference between stages was detected in the acceleration of the forearms where stage 1 was significantly different from stages 1, 2, 3, and 4.

Table 10
Resultant Accelerations at Takeoff

Variable (m/s/s)		Stage 1 (n=5)	Stage 2 (n=12)	Stage 3 (n=11)	Stage 4 (n=5)
Foot	M	29.70	26.74	27.85	24.97
	SD	±10.67	±7.21	±4.84	±6.46
Shank	M	16.56	17.76	19.27	19.41
	SD	±5.94	±5.03	±3.57	±2.18
Thigh	M	6.16[a]	8.69	10.36	14.18
	SD	±4.42	±4.45	±3.67	±1.85
Trunk	M	10.85[b]	9.25	9.01	6.65
	SD	±2.04	±2.14	±2.63	±1.18
Arm	M	15.26[c]	20.26	23.89	22.71
	SD	±5.47	±4.14	±3.95	±4.26
Forearm	M	17.66[d]	33.61	42.09	41.36
	SD	±8.60	±6.96	±7.66	±7.36
Head	M	15.22	14.34	15.08	12.77
	SD	±3.52	±3.04	±1.97	±2.35

[a] Significantly different from stage 4 ($p < .05$).
[b] Significantly different from stage 4 ($p < .05$).
[c] Significantly different from stages 3 and 4 ($p < .05$).
[d] Significantly different from stages 2, 3, and 4 ($p < .05$).

Kinetics

The resultant segmental force contributions at the moment of takeoff were calculated for each body segment. These values were found by multiplying corresponding body segment masses by resultant accelerations. The products represent the relative force contribution to the performance by each segment. Means and standard deviations for the resultant segmental force contributions at the moment of takeoff are given in Table 11.

A 7 (force contributions) X 4 (stage) MANOVA for the resultant segmental force contributions produced a significant Hotelling's value ($F[21, 65] = 3.02$, $p < .000$).

Table 11
Resultant Segmental Force Contributions at Takeoff

Variable (N)		Stage 1 (n=5)	Stage 2 (n=12)	Stage 3 (n=11)	Stage 4 (n=5)
Feet	M	62.05	48.58	53.46	47.12
	SD	±31.97	±16.15	±14.54	±18.82
Shanks	M	83.04	75.11	85.09	85.71
	SD	±56.04	±29.07	±22.58	±25.98
Thighs	M	65.15	73.19	88.34	116.06
	SD	±68.01	±49.82	±35.03	±45.79
Trunk	M	242.98	181.28	187.82	130.90
	SD	±98.10	±53.14	±73.75	±29.12
Arms	M	44.93	50.66	62.81	59.60
	SD	±28.79	±15.71	±16.46	±18.36
Forearms	M	31.29[a]	50.01	63.97	62.27
	SD	±23.79	±16.81	±12.59	±17.24
Head	M	142.27	117.45	125.85	97.50
	SD	±65.20	±31.62	±23.18	±25.01

[a] Significantly different from stages 3 and 4 ($p < .05$).

Univariate ONE-WAY procedures were conducted on each of the resultant segmental forces. The ONE-WAY analysis of variance revealed that only the resultant force of the forearms was significant ($F[3, 29] = 4.99$, $p < .007$). Subsequent Tukey post-hoc analysis indicated that stage 1 was significantly different than stages 3 and 4.

Peak ground reaction forces

Ground reaction forces were recorded during the performance of both the maximal jump for height and maximal jump for distance. The time of application of the force (Time) was recorded from the moment the vertical force differed from the subject's body weight until complete unweighting of the force platform. Peak vertical forces were normalized to

percent body weight for attempts to jump for maximal height (Pvf-h) and for distance (Pvf-d). Peak propulsive force for distance (Ppf-d), (reaction force in the direction of the jump), was also recorded. The magnitude of the resultant vector (Rv-d), calculated by using the horizontal and vertical components of the jump for distance at the moment of greatest propulsive force application was calculated. Angle of force (Af-d) is the angle, in degrees from horizontal, of the resultant force vector.

A 6 (ground reaction forces) X 4 (stage) MANOVA for peak ground reaction force parameters revealed a significant Hotelling's value ($F[18, 68] = 3.14$, $p < .000$). Therefore, the univariate ONE-WAY analysis of variance procedure was employed on each variable. The ONE-WAY analysis of variance indicated that peak propulsive force during the jump for maximal horizontal distance (Ppf-d) ($F[3, 29] = 15.67$, $p < .000$), resultant force vector during the jump for maximal horizontal distance (Rv-d) ($F[3, 29] = 3.56$, $p < .026$), and the angle of force production (Af-d) ($F[3, 29] = 3.55$, $p < .001$) were all significant.

Tukey post-hoc analysis showed that there was a significant difference for Ppf-d between stage 1 and stages 2, 3, and 4. For the variable Rv-d there was a significant difference between stage 1 and stage 2. The Af-d showed a significant difference between stage 1 and stages 2 and 4.

Multidimensional Scaling

Multidimensional scaling was used to compare the relationships of the variables within and across stages. The KYST2 program, which is an immediate successor to KYST, was used to perform the analysis. Twenty-three variables were included in the analysis (see Figure 12). An intercorrelation matrix was used as a proximity measure for input into the KYST2 program. The analysis was carried out for solutions of from 1 to 5 dimensions.

Table 12
Peak Ground Reaction Forces

Variable		Stage 1 (n=5)	Stage 2 (n=12)	Stage 3 (n=11)	Stage 4 (n=5)
Time (ms)	M	364.00	369.58	336.36	420.00
	SD	±73.60	±59.41	±59.54	±83.67
Pvf-h (%BW)	M	127.00	135.42	157.27	159.00
	SD	±30.94	±22.41	±28.93	±33.80
Ppf-d (%BW)	M	30.00[a]	67.50	66.83	63.00
	SD	±11.73	±11.97	±10.55	±8.37
Pvf-d (%BW)	M	93.00	123.75	115.00	107.00
	SD	±27.06	±31.34	±25.59	±28.20
Rv-d (%BW)	M	97.81[b]	142.19	133.56	125.40
	SD	±29.12	±27.34	±24.53	±21.89
Af-d (deg)	M	71.49[c]	60.46	61.40	58.36
	SD	±2.02	±7.93	±6.90	±8.81

Note. Variables are defined in the text.
[a] Significantly different from stages 2, 3, and 4 ($p < .05$).
[b] Significantly different from stage 2 ($p < .05$).
[c] Significantly different from stages 2 and 4 ($p < .05$).

A - Age (mths)
B - Weight (kg)
C - Distance jumped (m)
D - Time of application of force (ms)
E - X coordinate of toes from origin
F - Y coordinate of toes from origin
G - Total mass of body (kg)
H - Acceleration of feet (m/s/s)
I - Acceleration of shank (m/s/s)
J - Acceleration of thigh (m/s/s)
K - Acceleration of trunk (m/s/s)
L - Acceleration of arms (m/s/s)
M - Acceleration of forearms (m/s/s)
N - Acceleration of head (m/s/s)
O - Takeoff gain (m)
P - Landing gain (m)
Q - Angle of takeoff (deg)
R - Peak vertical force (height)
S - Peak propulsive force (distance)
T - Peak vertical force (distance)
U - Resultant vector of force (distance)
V - Angle of force application (distance)
W - Percent body fat

Figure 12. Variables for input into multidimensional scaling.

A four-dimensional solution was chosen on the basis of (a) an examination of increments in the decrease of the stress values as dimensions were added (see Figure 13), and (b) the interpretability of the dimensions (Arabie et al., 1987; Davison, 1983; Kruskal & Wish 1978).

Figures 14-17 present the items plotted by their stimulus coordinates for each pair of dimensions by stage. [The geometric shapes (circle, ellipse, square and rectangle) represent cluster membership to be discussed later.]

Interpretation of the dimensions underlying the item configuration was non-conclusive. To aid in the clarification of the dimensions, the stimulus coordinates for each dimension were correlated with the input variables (Kruskal & Wish, 1987). A maximum correlation coefficient of 0.518 for any single variable made the interpretation of dimensions impossible at this phase of the analysis.

The interpretation of the dimensions for the stimulus configuration is complimented by the results of a hierarchical centroid cluster analysis of the same items. A four-cluster solution was selected on the basis of increments in the objective function (error sum of squares within clusters) at each successive level of the combing process (Ward & Hock, 1963). The individual clusters are identified by the different geometric shapes used to signify membership. In each configuration (stage), a general cluster of variables were found to center around the origin. (Note: Stage 3 produced the greatest variability and cluster membership was not as clearly defined.) This result would imply that the general cluster was not defining any of the dimensions (Oltman et al., 1990). The variables that were best defining the dimensions were generally those associated with force production (kinetics).

The general clustering of the variables, as well as the lack of well-defined dimensions would imply that the collection of variables used for the unfolding may need to be reduced to a subset that better define the underlying structure of the activity. The use of a subset was supported by the non-significance of many of the variables in the multivariate

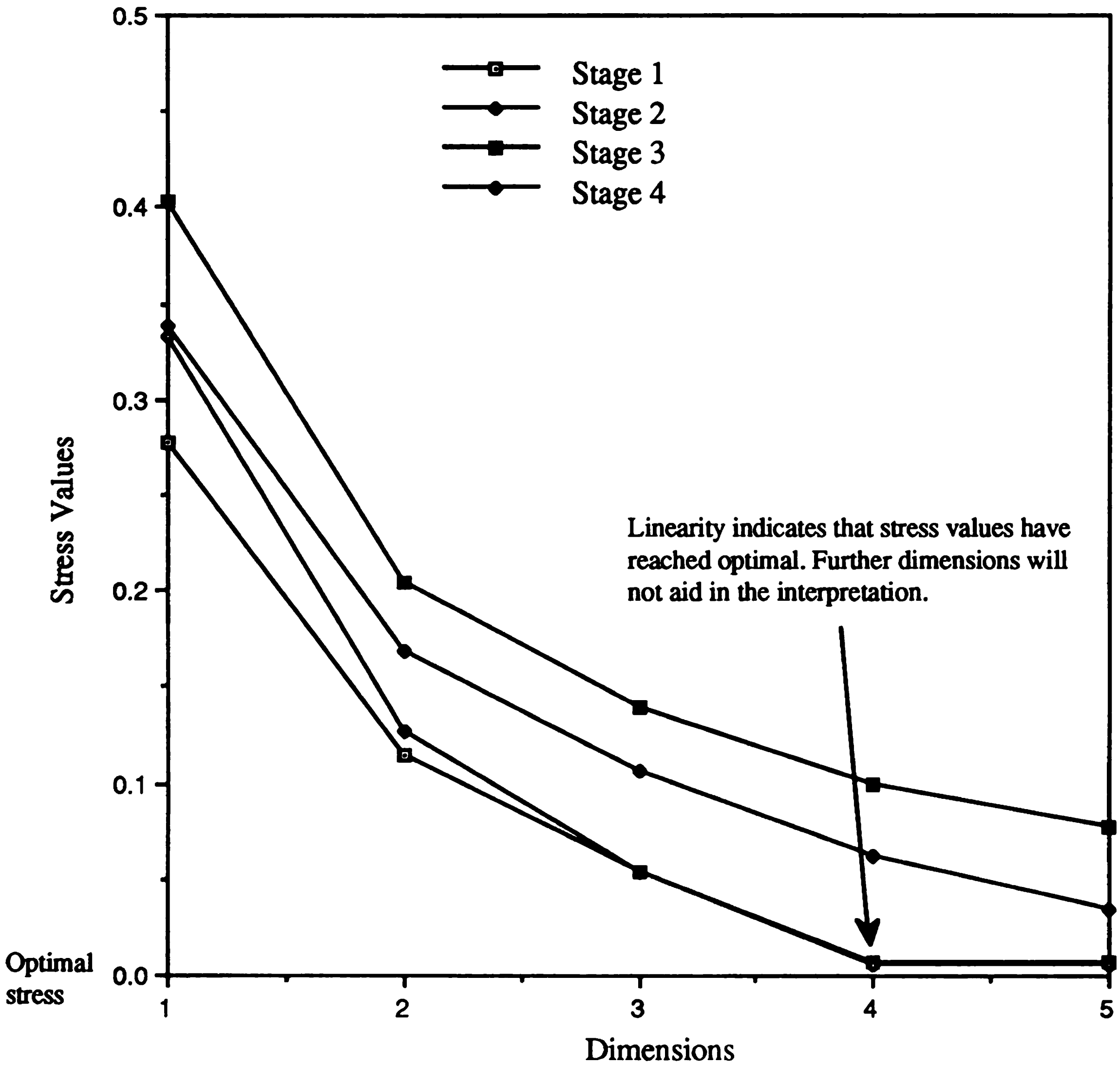

Figure 13. Plot of dimensions versus stress values for successive increments in dimensions.

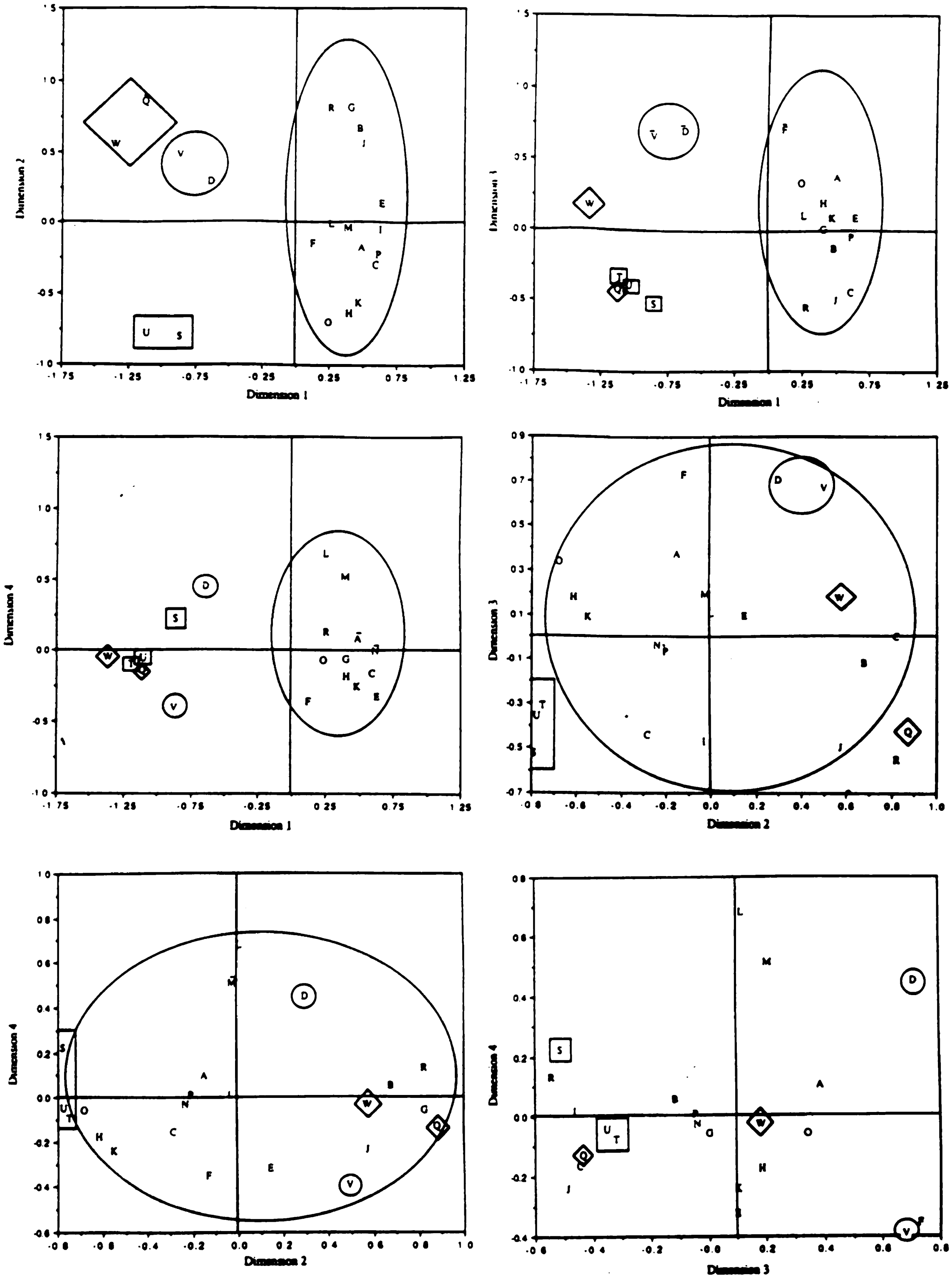

Figure 14. Plots of items' stimulus coordinates on dimensions for stage 1. (Cluster membership is depicted by shape - see text for explanations.)

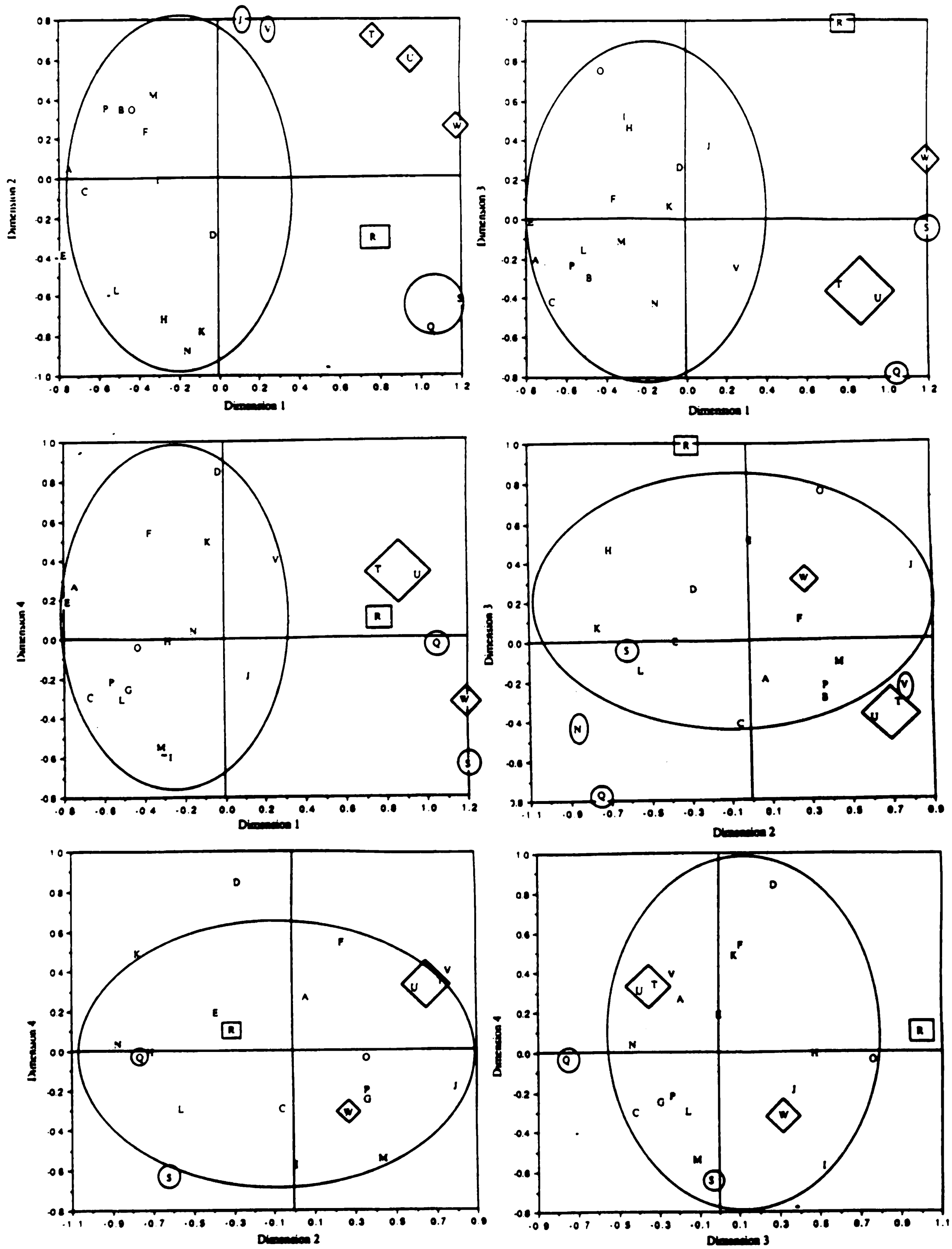

Figure 15. Plots of items' stimulus coordinates on dimensions for stage 2. (Cluster membership is depicted by figure shape - see text for explanation.)

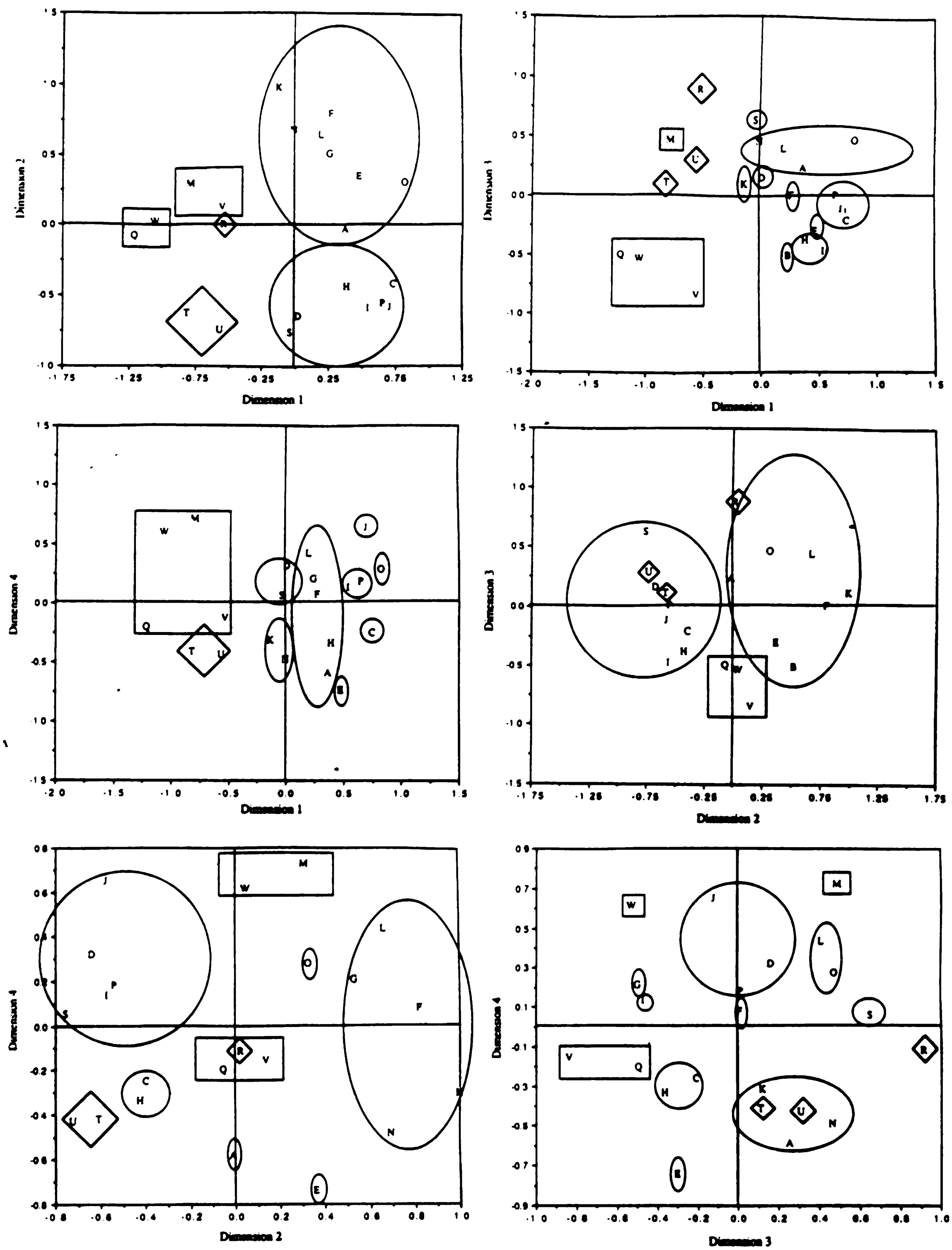

Figure 16. Plots of items' stimulus coordinates on dimensions for stage 3. (Cluster membership is depicted by figure shape - see text for explanation.)

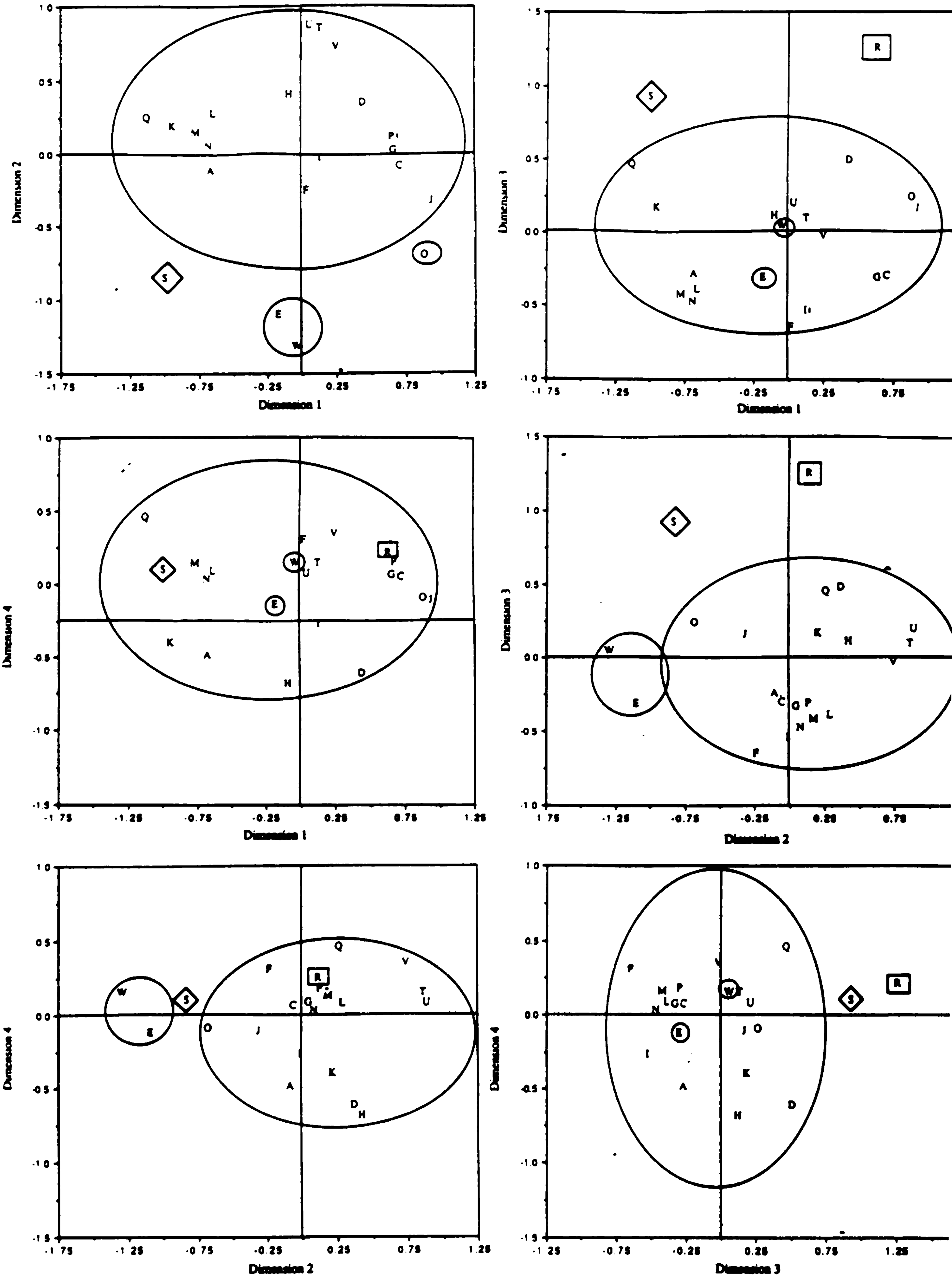

Figure 17. Plots of items' stimulus coordinates on dimensions for stage 4. (Cluster membership is depicted by figure shape - see text for explanation.)

and univariate tests of significance used to determine the ability of the variables to differentiate between stages.

Individual difference scaling

To gain insight into the relationships between the variables used to measure standing long jump ability and stages of development, an individual difference scaling procedure was performed. This procedure produces a stimulus plot of the individual subjects using the relationships between variables measured on individual subjects as input. The unfolding uses the Euclidean distance between each pair of variables as input, with each subject having an individual proximity matrix. The PROXIMITY routine in SPSS-X was used to generate the input matrices. The SINDSCAL individual difference program was used to analyze twenty of the same variables (see Figure 12) used in the KYST2 program. Age, weight and percent body fat were eliminated because these variables are not used to assess stages of standing long jump ability.

The SINDSCAL routine was run for solutions of from 2 to 5 dimensions. A three-dimensional solution was chosen on the basis of an examination of increments in the variance accounted for by successive solutions as dimensions were added (Arabie et al., 1987; Kruskal & Wish, 1978). This solution accounted for 49.6% of the variance (dimension 1 accounted for 23.8%, dimension 2 accounted for 19.4% and dimension 3 accounted for 6.4%).

Figure 18 presents the items plotted by their subject weights for each pair of dimensions. (The figures represent cluster membership to be discussed later.) The higher stages of performance generally had the highest subject weights on the dimensions. Dimension 2 is the only exception. Stage 1 performers scored relatively high on this dimension.

The interpretation of the dimensions from the SINDSCAL routine again produced

1 = stage 1
2 = stage 2
3 = stage 3
4 = stage 4

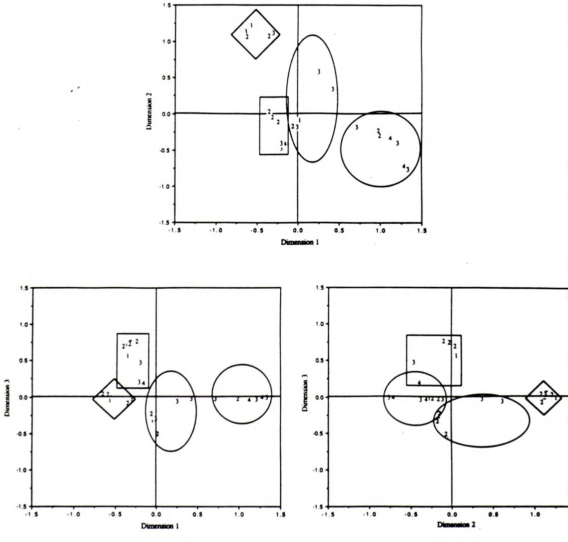

Figure 18. Plots of individual's stimulus coordinates by dimension. (Cluster membersh
is depicted by figure shape- see text for explanation.)

non-conclusive results. Correlations between all variables and the dimensions' stimu coordinates were low. Although the dimensions could not be interpreted, the results of cluster analysis did show a trend toward stage membership. No cluster containing a sta performer contained a stage 4 performer (opposite sides of the continuum). Each of clusters contain subjects from three of the four stages. However, viewing the stimulus from the upper left corner to the lower right, it would appear that an axis representativ some underlying variable is present. This variable was not apparent at this point in analysis. The clusters align themselves along this direction. In addition, the trend fr stage 1 to stage 4 follows this same direction.

Individual difference scaling of a subset of variables

Each of the statistical procedures performed have suggested that although the st construct may exist, confounding variables have clouded their interpretation. Therefor subset of five variables were chosen for further analysis based on the criterion that (a) variable shows a significant difference between stages in the univariate analysis of varia and (b) the variable is observable (directly or indirectly) in the performance of the stand long jump. Based on these criterion, five variables were chosen for further analysis: landing gain, (2) acceleration of the thigh, (3) acceleration of the trunk, (4) acceleratio the arms, and (5) acceleration of the forearms.

These five variables were used to generate a Euclidean dissimilarity matrix for e subject using the PROXIMITY routine in SPSS-X. The individual matrices were use input into the SINDSCAL individual difference routine. The results are presented in Fig 18. (Note: circles represent cluster membership to be discussed later.)

The SINDSCAL routine was run for solutions of from 2 to 4 dimensions. A t dimensional solution was chosen on the basis of an examination of increments in variance accounted for by successive solutions as dimensions were added (Arabie et

1987; Kruskal & Wish, 1978). This solution accounted for 94.3% of the variance (dimension 1 accounted for 67.0%, dimension 2 accounted for 27.3%).

Figure 19 shows that the subjects' item weights plotted by their stage membership align in a linear fashion. Together with the high percent of the variance accounted for by the two dimensions (94.3%), this configuration shows that the stage construct can be represented well by the subset of variables chosen. In addition, the ordering of the stages follow the proposed sequence (1 to 4) very well along an axis from top left to bottom right.

Cluster membership, represented by the circles, compliments the results of the individual difference scaling. Subjects within any particular stage of development cluster together in the same fashion shown by the SINDSCAL routine.

A correlation analysis of the subjects' weights with the other variables revealed that age correlated significantly (0.891). This would imply that the dimension underlying the linear trend of the data was age. Therefore, the movement from stage 1 to stage 4 was an age-related phenomenon. Although this cannot be taken to be age specifically, the dimension is related to age.

This result was further supported by the stage 1 out-lier shown in Figure 19 which was found to be a subject at the older end of the sample (an age 6 child within stage 1). Since this subject did not follow the age-related continuum, his/her stimulus coordinates lie outside the linear trend of the other subjects.

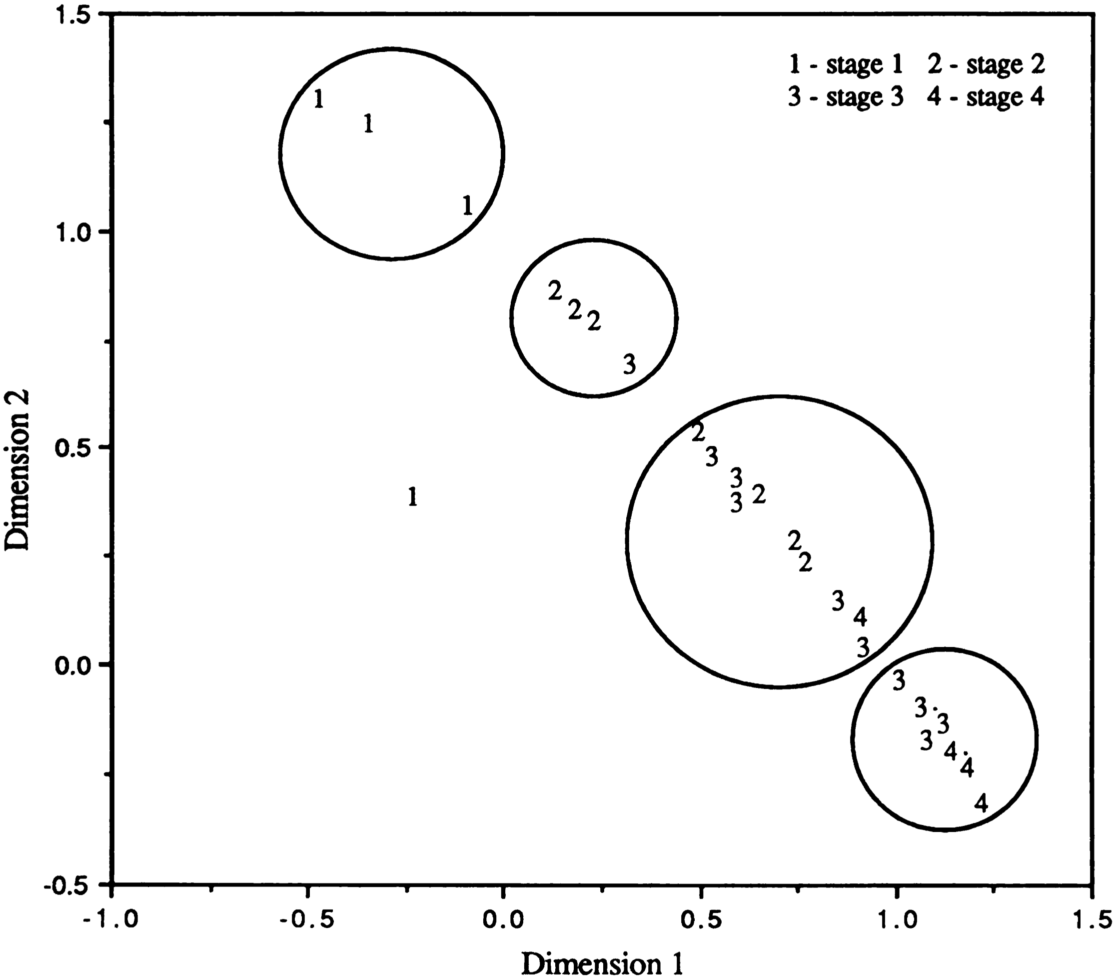

Figure 19. Plots of subsamples' subject weights on dimensions. (Subsample clusters are shown as circles.)

Chapter V

DISCUSSION AND CONCLUSIONS

The purpose of this investigation was to study a staging sequence of the standing long jump. In order to directly address the research questions posed, each will be discussed individually.

Research Question 1

Are the stages of the standing long jump related to the maturational characteristic of age?

The multivariate analysis of variance of the descriptive variables included age and was non-significant. Therefore, subsequent univariate ONE-WAY analysis of variance was not justified.

The multidimensional scaling of the variables revealed that age could not be separated from several extraneous parameters. Therefore, the relationship between age and the staging construct was uninterpretable at this phase of the analysis. This is most likely due to the fact that many of the variables included in the analysis did not discriminate between stages of standing long jump ability.

Individual difference scaling of the complete set of variables did not include age. Age was excluded because it is not used to define stages of motor development. Individual difference scaling of the subset of variables did reveal that age was the significant determinant of the staging sequence. This result was supported by the cluster analysis of the subjects' stimulus weights.

This finding has significant importance for the use of the staging sequence to evaluate standing long jump ability. Although several variables (e.g., age, learning effect,

power) could be hypothesized as underlying the progression of ability, age was the only variable found to significantly correlate with the INDSCAL subject weights. Therefore, the results would suggest that the staging sequence is primarily due to the natural progression of a child as he/she matures. This is not to imly that teaching/intervention is not important, but rather that the impact of a learning effect seems to be less than the natural maturational effect.

Research Question 2

Are the stages of the standing long jump related to body composition (percent body fat) and size (segmental masses)?

The multivariate analysis of variance for body mass characteristics revealed a non-significant Hotelling's value ($F[24, 62] = 1.25$, $p < .239$). Subsequent univariate tests were unsupported. Percent body fat was included in the MANOVA results of the first research question which was non-significant.

Multidimensional scaling of the segmental masses was not performed as these are not used to assess stages of performance. Therefore, the results of this study would indicate that body mass, individual segmental masses, and percent body fat are not related to the staging sequence investigated.

Davies and Rennie (1968) and Payne et al. (1968) suggested that because the vertical acceleration tends to remain constant in jumping activities, mass would be the only factor that differentiates between age groups. The results of this study would not support either assertion. While the acceleration values showed few statistical differences between stages, there was a progression toward increasing acceleration for the more mature patterns. In addition, the mass differences between stages were not evident. This data would suggest that it is not the greater body mass that results in increased jumping distances

Research Question 3

Does the objective of the standing long jump (distance) differentiate between the developmental stages of the performance?

The overall multivariate analysis of variance for distance and positional characteristics produced a significant Hotelling's value ($F[12, 74] = 2.13$, $p < .006$). The ONE-WAY analysis of variance of the distance jumped was also significant ($F[3, 29] = 5.03$, $p < .006$). Tukey post-hoc analysis revealed that stages 1 and 2 were significantly different from stage 4 at the .05 level.

The multidimensional scaling results showed that distance jumped did not unfold near the origin, but along one of the dimensions. Variables that are found near the origin of a configuration are interpreted as not defining any of the dimensions. As a variable moves along any particular dimension, its relationship to that dimension, and therefore its ability to define that dimension, increases. In stage 3, distance clustered together with the propulsive force and the acceleration of the feet. This would indicate that distance was differentiating stages along one of the dimensions.

These results show that distance jumped is related to the stages of motor performance. Although significant differences were not found between each of the individual stages, this could be attributed to the relatively low number of subjects within stages. In addition, the stage means for distance jumped increased with each successive stage.

This result would lend support to the use of the staging sequence as a method of assessing increased performance. The individual stages were evaluated on the basis of body configurations and temporal sequencing up to the moment of takeoff. The objective of these body segment manipulations was to maximize jumping distance. The distance jumped showed a clear progression between each stage toward a more mature jumping

of these body segment manipulations was to maximize jumping distance. The distance jumped showed a clear progression between each stage toward a more mature jumping pattern and an increasing performance. The ability of the staging sequence to relate the biomechanical factors of the jump to the end product was significant.

Biomechanical assessment of jumping patterns would be far too expensive and time consuning for the practioner in the field. The ability of the staging sequence to identify the factors that contribute to better performance offer a viable alternative to physical educators. Using the staging sequence, children can be assessed quickly with reasonable accuracy as to their ability to perform the standing long jump.

Research Question 4

Are the stages of the standing long jump differentiable by body orientation at takeoff and landing?

To answer this question, body lean was measured during the takeoff of the standing long jump. Gain due to the distance between the center of mass of the body and the nearest point on the body to the takeoff mark was measured at takeoff (takeoff gain) and landing (landing gain). The relative position of the body was measured using the angle of inclination at the moment of takeoff.

The overall multivariate analysis of variance produced a significant Hotelling's value ($F[12, 74] = 2.13$, $p < .006$) for these four variables. Univariate ONE-WAY tests for each variable revealed that only the landing gain ($F[3, 29] = 6.65$, $p < .001$) accounted for significant variance between stages. Tukey post-hoc analysis showed that stages 1, 2 were significantly different than stage 4.

Multidimensional scaling showed that each of the body position variables were located away from the origin of the configurations. This would imply that these variables were related to one of the dimensions within the configuration(s). Additionally, these variables clustered together with a small number of other variables indicating that they

were important to defining one of the dimensions. This would lead to the conclusion that body position, most notably at the point of landing, is an important characteristic to observe during the performance of the standing long jump.

The only body orientation variable that was found to statistically discriminate between stages was landing gain. Interestingly, landing gain accounted for 67% of the increased distance jumped between stages 1 and 2, 81% between stages 2 and 3, and 81% between stages 3 and 4. These percentages would indicate that the position at landing is the most important variable to the objective (distance jumped). This has implications as to the validity of the staging sequence proposed by Seefeldt et al. (1972).

In their sequence, Seefeldt et al. (1972) state that the position of the thigh relative to horizontal at landing is a critical component to the identification of stages 3 and 4. This visual cue greatly increases the validity of their staging sequence as this component seems to be critical to identifying jumping ability. A sequence that does not use the position of the body at the moment of landing would be greatly lacking in the ability to identify increasing levels of performance.

Research Question 5

Are the stages of the standing long jump differentiable by the contributions of the individual body segments (acceleration, force)?

Resultant segmental accelerations produced a significant Hotelling's value ($F[12, 74] = 2.13$, $p < .006$) in the multivariate analysis of variance. ONE-WAY univariate analysis of variance revealed that the acceleration of the thigh ($F[3, 29] = 3.91$, $p < .019$), acceleration of the trunk ($F[3, 29] = 3.10$, $p < .042$), acceleration of the arms ($F[3, 29] = 5.00$, $p < .006$), and the acceleration of the forearms ($F[3, 29] = 13.51$, $p < .000$) were all significant at the .05 level.

Tukey post-hoc analysis showed that for the acceleration of the thigh and trunk, stage 1 was significantly different than stage 4. The acceleration of the arms was

significantly different between stage 1 and stages 3 and 4. The only variable that encompassed all stages was the acceleration of the forearms, where stage 1 was found to be significantly different from stages 2, 3, and 4 at the .05 level.

The overall multivariate analysis of variance for the segmental force contributions resulted in a significant Hotelling's value ($F[21, 65] = 3.02$, $p < .000$). Subsequent univariate ONE-WAY procedures revealed that only the force of the forearms was significantly different ($F[3, 29] = 4.99$, $p < .007$) across stages. Tukey post-hoc analysis indicated that stage 1 was significantly different from stages 3 and 4.

These results would support the assertion that stages of motor ability are related to the contributions of the body segments. In particular, the movement of the arms and forearms seem to be a vital component in assessing the motor proficiency of a child performing the standing long jump. To a lesser degree, the acceleration of the larger body segments (thigh, trunk) provide information about the ability of a child to perform this skill. The key observable characteristic of all these variables would be not only the magnitude of the acceleration during performance, but the direction and temporal sequencing of the segments in relation to the other body components. Although these variables were not included in this study, a recommendation to include these variables in further research is made at the end of this chapter.

Research Question 6

Can stage theory as a construct be validated using multidimensional scaling?

The key factors that allowed for the assessment of this question were (1) the relationships between the variables that defined the performance and (2) the ordering of these relationships with respect to performance. The relationships between the variables were used to generate a proximity matrix that served as the input for the multidimensional scaling. This process was carried out for each individaul stage. The

results of this process were inconclusive as variables not discriminating between stages made interpretation impossible.

The set of variables used as input was reduced to a subset of five variables that discriminated between the stages of motor ability very well. Individual difference scaling of this subset of variables revealed a clear linear pattern of progression from stage 1 to stage 4. Age was found to be the variable underlying the main dimension of the configuration.

Multidimensional scaling was chosen as a tool for investigating a developmental staging sequence because of its potential to validate the sequence. The assumption made was that if the staging sequence under invetigation is valid, the sequence would validate itself empirically. Thus, the ordering of the sequence's biomechanical parameters should hold regardless of any a priori knowledge concerning stage membership.

The biomechanical factors that determine jumping proficiency were collected and analyzed using both multidimensional scaling and individual difference scaling. MDS was unable to validate or invalidate the staging sequence. Individual difference scaling was able to validate the staging sequence. This was accomplished once the correct subset of variables was identified. The original set of variables was designed to provide a complete set of factors related to the performance. Due to a lack of previous investigation in this area, it was not known whether this collection of variables would be incomplete or contain extraneous parameters. However, the deterministic model was useful in providing a starting point for identifying the most important factors related to the performance of the standing long jump.

The central question of whether the stages of the standing long jump exist is subject to further study. However, the results of this investigation would lead the auther to the conclusion that the stages do exist and provide a useful tool for the practitioner in assessing jumping proficiency. There is, however, the possibility of refining the visual cues used in evaluating the individual stages.

From these results, it is concluded that multidimensional scaling and individual difference scaling can be useful tools in studying the relationships of the parameters of performance of motor skills to the objective of the performance. In addition, these techniques can aid in the interpretation of the factor(s) that relate to the achievement of greater motor proficiency.

Implications for Teachers of Fundamental Motor Skills

The fundamental motor skill (standing long jump) studied in this investigation is one of several (e.g., running, kicking, striking) that are routinely taught in physical education classes. Stages of motor development have been proposed by numerous authors (see Table 1, Chapter II) in order to assist teachers of these skills in assessing the level of development, and subsequently provide instruction to aid the performer in skill enhancement.

Within the limitations imposed by this study, the following implications can be inferred to assist the instructors of the standing long jump, and more broadly, jumping skills in general.

To assess the performance of the standing long jump, the subset of observable physical characteristics may be reduced to (1) the position of the body at the moment of landing, (2) the acceleration of the thighs at takeoff, (3) the acceleration of the trunk at takeoff, (4) the acceleration of the arms at takeoff, and (5) the acceleration of the forearms at takeoff.

The first characteristic, position at landing, is included in Seefeldt et al.'s (1972) model of the standing long jump. The specific teaching cue that allows for greater differentiation between levels of development is the position of the thigh relative to the horizontal at landing. A position close to horizontal will allow the performer to maximize the distance attained for the event, as well as assist in a forward movement to prevent

falling back during landing.

The next two characteristics, acceleration of the thigh and trunk are mainly a function of the direction of the resultant acceleration. Horizontal, vertical and resultant accelerations were recorded. The resultant acceleration includes the angle of application of the acceleration. Thus, movement of the thigh and trunk to a position in line with the intended direction of the jump at takeoff (full extension) is desirable.

The last two characteristics, acceleration of the arms and forearms give distinct clues to the level of motor ability. In Seefeldt et al.'s (1972) model of the standing long jump, stage 1 is characterized by movement of the arms backward, acting as brakes to stop the momentum of the trunk during takeoff. In stage 2, the arms move in an anterior-posterior direction during the preparatory phase, and sideward (winging action) during the "in-flight" phase. Stages 3 and 4 show the arms moving in the direction of the jump synchronously with the other body segments. The movement of the arms would thus be an easily observable teaching cue to aid in the assessment of motor proficiency.

Recommendations for Further Study

The use of multidimensional scaling and individual difference scaling represent a new approach to the investigation of developmental progressions of motor skills in children. In order to develop this procedure, the following recommendations for further research are offered.

1) This study should be replicated using a greater number of subjects within each stage. The relatively low N made statistical treatment of many of the variables difficult to interpret.

2) The variables used to investigate the standing long jump should be expanded to include more precise temporal and body segment relationships. For example, intersegmental angles at each event (takeoff, landing).

3) The analysis should be expanded to include three-dimensional cinematography. This would allow the researcher to identify any non-bilateral movements that may confound the variables under study.

4) The analysis should include a measure of the sequencing of movements (e.g., proximal to distal) in order to determine if this is one of the key elements in the progression from one stage to another.

5) The study should be conducted using the models proposed by other authors in order to compare the cues for individual motor skills.

APPENDIX A

Anthropometric Measurements

ANTHROPOMETRIC MEASURES

Subject's Name______________________ Date_____________________

Address____

Subject Number_____________________ Telephone (_____)____________

__________ Weight (1/4 lb.)

__________ Forearm length (radio-stylion)

__________ Brachium length (acrom-radiale)

__________ Thigh-plus-leg length

__________ Leg length

__________ Upper extremity length

__________ Standing height

__________ Trochanteric height

__________ Seventh cervical height

__________ Sitting height

__________ Head-plus-neck length*

__________ Trunk length*

__________ Thigh length*

__________ Functional leg length*

* derived measures

__________ Neck girth

__________ Shoulder girth

__________ Chest girth

__________ Abdominal - 1 girth

__________ Abdominal - 2 girth

__________ Hip girth

__________ Thigh girth

__________ Calf Girth

__________ Biceps girth (elbow ext.)

__________ Biceps girth (elbow flx.)

__________ Forearm girth

__________ Supra-iliac skinfold

__________ Thigh skinfold

__________ Calf Skinfold

__________ Subscapular skinfold

__________ Triceps skinfold

__________ Biceps skinfold

__________ Percent body fat*

Anthropometrist ________________________________

APPENDIX B

Informed Consent and Information Flyers

Parental Consent Form
Standing Long Jump Study

This investigation is being conducted in order to determine developmental parameters that contribute to the proper performance of the standing long jump. High-speed cinematography will be used to film children performing two trials of the standing long jump. Additionally, anthropometric (e.g., height, weight, body segment length, girths, skinfolds) measurements will be taken by skilled researchers familiar with these procedures. Skinfold measurements are external, non-invasive 'pinches' of skin used to assess body composition.

Each child will require approximately one hour to complete all measurements. These procedures will be explained to the child, and every effort will be made to make the child comfortable. Your child's choice to participate in this study is completely voluntary and your child may discontinue involvement in the study at any time.

The data collected will be kept in strict confidence, with no one knowing the identity of your child other than the principal investigator (Mr. Daniel Wilson, Doctoral Candidate, Michigan State University). Film records will be used for data collection and presentations associated with this study only. Your child's identity will not be revealed. Any part of your child's data may be requested by the parent or guardian and will be made available as soon as possible. No beneficial results are guaranteed as a result of participation in this study. Performance, anthropometric, and strength measures will be given to parents or guardian if requested. The child must agree verbally to participate in this study. Written consent from the parent or guardian will also be obtained.

If you have any questions or concerns regarding this study, please feel free to contact the principal investigator at any time.

Parent's Signature______________________________ Date____________________

Principle Investigator: Daniel Wilson, Doctoral Candidate
Department of Physical Education and Exercise Science
Michigan State University
(517) 347-1739 (Home)
(517) 353-0892 (Office)

MICHIGAN STATE UNIVERSITY

COLLEGE OF EDUCATION
DEPARTMENT OF PHYSICAL EDUCATION AND EXERCISE SCIENCE
I M SPORTS CIRCLE

EAST LANSING • MICHIGAN • 48824-1049

Dear Parent/Guardian:

Over its 24-year history, the Motor Performance Study has had three primary functions; namely, to provide instruction in skills and games to children, to provide a laboratory setting for prospective teachers of physical education to learn about children and how to teach motor skills and activities to them, and to conduct research on how children grow and how they develop motor skills. The first two functions are usually obvious on Saturday mornings and during the summer program, the research function is less apparent.

Across the years, both faculty and graduate students have studied various aspects of child growth and development, including motor skill learning, physiological fitness, developmental sequencing of skills, and cognitive aspects of learning motor skills. Currently, one of our doctoral students, Daniel Wilson, is interested in examining the development of the standing long jump from a biomechanical perspective. The type of research he is proposing not only can provide us with statistical support for what we have learned through visual observation and filming of the movement behavior of children, but it may also provide physical education teachers with additional clues on how the development of jumping skills can be enhanced.

As a member of Mr. Wilson's doctoral guidance committee and as Coordinator of the Motor Performance Study, I strongly endorse this research project because of its potential contribution to the education of children and youths. I encourage the involvement of your child in this project. I believe that he or she will enjoy it as a unique experience.

I refer you to the materials enclosed for details about the study, and to Mr. Wilson for specific questions, however, I would be happy to attempt to answer any general questions you may have about the project.

Thank you and your child for giving consideration to this invitation.

John L. Haubenstricker

John L. Haubenstricker

Professor and Coordinator
Motor Performance Study
(517) 355-4741

MICHIGAN STATE UNIVERSITY

COLLEGE OF EDUCATION
DEPARTMENT OF PHYSICAL EDUCATION AND EXERCISE SCIENCE
I M SPORTS CIRCLE

EAST LANSING • MICHIGAN • 48824-1049

March 27, 1992

Dear Parent/Guardian:

Over its 14-year history, the Early Childhood Program has had three primary functions; namely to provide instruction in skills and games to children, to provide a laboratory setting for prospective teachers of physical education to learn about children and how to teach motor skills and activities to them, and to conduct research on how children grow and how they develop motor skills. The first two functions are usually obvious during class time, the research function is less apparent.

Across the years, both faculty and graduate students have studied various aspects of child growth and development, including motor skill learning, physiological fitness, developmental sequencing of skills, and cognitive aspects of learning motor skills. Currently, one of our doctoral students, Daniel Wilson, is interested in examining the development of the standing long jump from a biomechanical perspective. The type of research he is proposing not only can provide us with statistical support for what we have learned through visual observation and filming of the movement behavior of children, but it may also provide physical education teachers with additional clues on how the development of jumping skills can be enhanced.

As the Director of the Early Childhood Program, I strongly endorse this research project because of its potential contribution to the education of children and youths. I encourage the involvement of your child in this project. I believe that he or she will enjoy it as a unique experience.

I refer you to the materials enclosed for details about the study, and to Mr. Wilson for specific questions; however, I would be happy to attempt to answer any general questions you may have about the project.

Thank you and your child for giving consideration to this invitation.

Tina G. Cate

Tina G. Cate

Instructor and Director
Early Childhood Program
(517) 353-3866

APPENDIX C

Individual Subject Information

Subject Description

ID	Age[1]	Sex	Weight	Dist.[2]	Stage	Time[3]	Takeoff[4]	Landing[5]
01	75	M	23.70	0.95	3	250	1.17, 0.59	1.63, 0.43
02	76	M	18.14	1.20	4	350	0.92, 0.49	1.51, 0.32
03	82	M	22.00	1.07	2	430	1.33, 0.58	1.77, 0.39
04	82	M	35.49	1.03	1	350	1.33, 0.53	1.83, 0.35
05	80	M	20.18	0.84	2	430	0.92, 0.52	1.30, 0.35
06	80	M	22.70	1.04	2	400	1.01, 0.53	1.54, 0.39
07	87	M	25.29	0.77	1	450	1.25, 0.81	1.59, 0.60
08	66	F	23.13	1.30	3	300	1.16, 0.48	1.73, 0.27
09	83	F	18.37	1.02	3	275	1.29, 0.49	1.75, 0.33
10	85	M	26.76	1.51	4	550	0.94, 0.54	1.76, 0.32
11	63	M	22.57	0.81	1	270	1.13, 0.52	1.46, 0.41
12	82	M	27.56	1.15	3	400	1.14, 0.54	1.67, 0.41
13	85	M	20.87	1.36	3	400	0.99, 0.49	1.61, 0.35
14	69	F	14.29	0.53	2	300	0.77, 0.34	1.03, 0.24
15	82	M	28.24	1.11	2	400	0.93, 0.53	1.52, 0.35
16	84	M	21.09	1.14	3	425	0.97, 0.50	1.46, 0.37
19	92	M	18.71	1.21	4	400	0.97, 0.53	1.54, 0.38
20	71	M	18.71	1.21	3	350	0.97, 0.46	1.58, 0.26
21	84	F	24.72	1.46	4	350	1.01, 0.57	1.77, 0.41
22	64	F	22.68	0.92	3	300	0.90, 0.53	1.37, 0.40
23	81	M	18.37	1.23	4	450	0.97, 0.48	1.54, 0.32
24	81	M	21.66	1.29	2	425	1.08, 0.65	1.61, 0.43
25	89	M	27.44	1.16	3	375	1.02, 0.63	1.54, 0.44
26	70	M	23.47	1.01	2	250	0.99, 0.46	1.45, 0.34
28	80	M	24.27	1.30	2	350	0.96, 0.57	1.58, 0.40
29	66	M	20.30	1.18	2	350	0.75, 0.34	1.55, 0.29
30	71	M	18.82	0.87	1	325	0.98, 0.46	1.31, 0.32
33	60	F	18.60	0.75	2	300	0.93, 0.41	1.27, 0.34
35	71	M	18.82	0.87	3	275	0.88, 0.42	1.27, 0.29
36	57	M	21.09	0.35	1	425	0.81, 0.39	0.99, 0.33
37	59	F	19.62	0.84	2	400	0.88, 0.40	1.26, 0.26
39	57	M	20.41	0.61	3	350	0.70, 0.48	0.99, 0.33
40	57	F	16.78	0.45	2	400	0.70, 0.54	0.92, 0.39

[1] Age as of March 1, 1992 (Testing Date).
[2] Distance (horizontal) jumped.
[3] Time of application of force.
[4] Center of mass (x,y) at takeoff.
[5] Center of mass (x,y) at landing.

Body Segment Masses (lbs)[1]

ID	Total	Foot[2]	Shank[2]	Thigh[2]	Trunk	Arm[2]	Forearm[2]	Head
01	52.25	2.04	4.74	9.22	22.00	2.82	1.64	8.84
02	40.00	1.57	3.63	7.05	16.84	2.16	1.26	6.77
03	48.50	1.90	4.40	8.55	20.42	2.62	1.53	8.21
04	78.25	3.07	7.11	13.80	32.94	4.23	2.47	13.24
05	44.50	1.74	4.04	7.85	18.73	2.41	1.40	7.53
06	50.00	1.96	4.54	8.82	21.05	2.70	1.58	8.46
07	55.75	2.20	5.20	10.24	23.44	3.11	1.78	8.80
08	51.00	1.98	4.51	8.62	21.50	2.67	1.59	9.21
09	40.50	1.59	3.68	7.14	17.05	2.19	1.28	6.85
10	59.00	2.33	5.50	10.83	24.80	3.29	1.88	9.31
11	49.75	1.94	4.40	8.41	20.97	2.61	1.55	8.98
12	60.75	2.38	5.52	10.71	25.58	3.29	1.92	10.28
13	46.00	1.82	4.29	8.45	19.34	2.56	1.47	7.26
14	31.50	1.23	2.78	5.33	13.28	1.65	0.98	5.69
15	62.25	2.44	5.65	10.98	26.21	3.37	1.96	10.53
16	46.50	1.84	4.34	8.54	19.55	2.59	1.48	7.34
19	41.25	1.63	3.85	7.58	17.34	2.30	1.32	6.51
20	41.25	1.60	3.65	6.97	17.39	2.16	1.29	7.45
21	54.50	2.15	5.08	10.01	22.91	3.04	1.74	8.60
22	50.00	1.95	4.42	8.45	21.08	2.62	1.56	9.03
23	40.50	1.59	3.68	4.85	17.05	2.19	1.28	6.85
24	47.75	1.87	4.34	8.42	20.10	2.58	1.51	8.08
25	60.50	2.39	5.64	11.11	25.43	3.37	1.93	9.55
26	51.75	2.01	4.57	8.75	21.82	2.71	1.61	9.35
28	53.50	2.10	4.86	9.44	22.52	2.89	1.69	9.05
29	44.75	1.74	3.96	7.57	18.87	2.34	1.40	8.08
30	33.00	1.28	2.92	5.56	13.92	1.73	1.03	5.96
33	41.00	1.59	3.62	6.93	17.29	2.15	1.28	7.40
35	41.50	1.61	3.67	7.02	17.50	2.17	1.29	7.49
36	46.50	1.79	4.00	7.52	19.63	2.36	1.43	8.93
37	43.25	1.67	3.72	7.00	18.26	2.19	1.33	8.30
39	45.00	1.74	3.87	7.28	19.00	2.28	1.39	8.64
40	37.00	1.43	3.18	5.99	15.69	1.88	1.14	7.10

[1] Body segment masses calculated from: Jensen, R. E. (1986) Body segment mass, radius and radius of gyration proportions of children. Journal of Biomechanics, 19, 359-368.
[2] Total includes both sides of the body.

Anthropometric Measures (cm)

ID	Fa[1]	Br[2]	Tl[3]	Lg[4]	Ue[5]	Tr[6]	Th[7]	Fl[8]	Hn[9]
01	21.2	24.3	58.2	28.8	54.5	47.8	29.4	57.4	22.9
02	18.3	22.1	49.7	25.8	48.6	41.9	23.9	49.4	21.2
03	20.4	23.9	55.8	28.7	53.8	46.5	27.1	56.0	21.0
04	21.5	24.9	57.4	30.7	55.4	48.4	26.7	57.8	22.5
05	18.1	20.5	48.1	24.6	47.1	40.5	23.4	51.7	20.6
06	19.0	22.7	52.8	26.6	50.7	45.4	26.2	52.6	22.6
07	22.8	25.7	62.9	31.2	58.5	46.6	31.7	62.6	24.4
08	18.9	22.7	54.0	28.3	49.9	46.3	25.7	52.7	19.3
09	19.1	22.3	54.6	26.7	50.6	40.6	27.9	53.0	19.0
10	20.7	24.3	58.4	30.2	55.3	48.2	28.2	58.3	21.5
11	19.8	22.1	51.7	26.6	50.3	43.7	25.1	51.3	21.5
12	20.6	24.9	58.8	29.5	54.5	46.0	29.3	57.4	21.7
13	20.0	24.0	56.1	29.0	52.7	44.3	27.1	55.7	20.2
14	16.7	19.9	45.2	23.3	44.0	36.1	21.9	44.7	19.9
15	22.1	25.2	59.2	30.5	56.5	48.4	28.7	57.7	22.8
16	19.6	23.0	55.6	28.7	51.3	42.9	26.9	54.1	22.2
19	19.3	22.2	53.0	28.2	50.8	44.6	24.8	53.8	22.8
20	18.8	21.8	51.9	25.6	49.2	39.4	26.3	52.3	20.7
21	19.9	23.6	66.7	28.7	52.8	48.6	38.0	55.4	19.9
22	20.5	23.3	54.6	28.8	51.4	43.5	25.8	53.1	22.6
23	18.5	21.1	49.4	26.0	47.4	40.3	23.4	49.9	19.8
24	20.6	22.9	54.0	28.8	52.8	44.4	25.2	53.0	21.2
25	21.4	24.7	57.8	30.4	54.8	46.6	27.4	57.6	21.9
26	19.2	23.1	50.5	26.1	48.5	43.0	24.4	50.0	21.6
28	21.1	23.8	56.4	29.5	54.2	48.5	26.9	56.2	21.3
29	19.1	21.4	50.1	26.5	49.2	36.5	23.6	53.7	21.5
30	17.2	19.6	46.0	23.4	44.5	38.7	22.6	45.5	19.2
33	19.0	21.3	51.0	25.8	49.9	39.7	25.2	51.6	20.7
35	18.8	22.6	50.3	26.0	48.3	38.7	24.3	50.0	20.8
36	17.6	20.2	43.1	22.8	44.7	39.9	20.3	46.2	20.8
37	17.1	18.2	46.3	23.7	43.6	39.4	22.6	47.3	19.1
39	14.5	19.5	39.5	20.2	42.5	37.3	19.3	45.1	20.1
40	16.5	18.6	43.0	22.2	45.0	38.9	20.8	46.5	18.4

[1] Forearm length
[2] Brachium length
[3] Thigh + leg length
[4] Leg length
[5] Upper extremity length
[6] Trunk length
[7] Thigh length
[8] Functional leg length
[9] Head + neck length

Anthropometric Measures (heights and girths)

ID	Sh[1]	Th[2]	7c[3]	St[4]	Ng[5]	Sg[6]	Cg[7]	A1[8]
01	128.1	62.8	105.2	70.7	25.5	71.0	58.4	53.8
02	112.5	53.1	93.1	63.1	23.4	66.0	54.1	49.0
03	123.5	59.7	102.5	67.5	25.7	70.0	57.2	52.1
04	128.7	61.4	106.2	70.9	29.9	86.6	72.3	66.0
05	112.8	52.4	92.2	61.1	25.0	67.5	56.7	53.3
06	120.6	58.2	98.0	68.0	25.7	70.8	50.4	52.8
07	133.6	67.1	109.2	71.0	27.0	77.9	60.6	56.8
08	118.0	57.6	98.7	65.3	24.7	70.5	58.2	55.2
09	112.6	78.0	93.6	59.6	24.0	65.3	53.1	51.0
10	128.0	62.4	106.5	69.7	28.2	76.1	60.7	59.0
11	116.5	54.6	95.0	65.2	27.2	68.5	59.2	54.2
12	125.1	62.3	103.4	67.7	26.0	73.0	62.8	59.8
13	120.2	79.7	100.0	64.5	25.9	71.0	55.7	50.1
14	100.7	48.0	80.8	56.0	22.9	64.0	51.1	47.5
15	128.9	63.0	106.1	71.2	27.7	79.2	65.8	61.5
16	119.2	58.6	97.0	65.1	24.8	69.8	59.1	52.7
19	121.2	57.1	98.4	67.4	24.6	72.2	60.2	55.0
21	123.9	60.3	104.0	68.5	26.5	72.8	61.5	57.0
22	119.2	57.1	96.6	66.1	25.6	71.5	56.1	52.6
23	110.0	53.3	90.2	60.1	24.3	68.2	56.3	49.7
24	118.6	58.5	97.4	65.6	24.7	70.1	59.7	56.1
25	126.1	62.5	104.2	68.5	27.2	74.7	62.0	59.8
26	114.6	54.5	93.0	64.6	26.3	71.6	59.6	57.3
28	126.0	60.1	104.7	69.8	26.3	74.3	60.9	56.1
29	111.7	53.6	90.2	58.0	26.1	67.7	59.3	53.6
30	103.4	48.6	84.2	57.9	21.8	62.8	50.7	46.1
33	112.0	54.2	91.3	60.4	24.2	65.5	53.5	51.0
35	109.5	53.1	88.7	59.5	24.7	67.1	56.3	52.1
36	106.9	48.2	86.1	60.7	28.1	70.2	58.7	58.4
37	105.8	49.9	86.7	58.5	25.2	67.7	56.4	53.7
39	102.5	45.7	82.4	57.4	26.5	68.4	58.0	57.0
40	103.8	48.6	85.4	57.3	23.8	67.5	56.0	53.0

[1] Standing height [2] Trochanteric height [3] Seventh cervical height
[4] Sitting height [5] Neck girth [6] Shoulder girth
[7] Chest girth [8] Abdominal 1 girth

Anthropometric Measures (heights and girths)

ID	A2[1]	Hg[2]	Tg[3]	Cg[4]	Be[5]	Bf[6]	Fa[7]
01	54.8	63.2	34.0	24.3	17.1	18.4	18.1
02	47.3	54.1	29.4	22.0	14.8	16.1	16.2
03	55.0	59.3	32.4	22.5	15.7	17.3	16.7
04	69.7	75.4	45.2	30.2	23.4	26.2	21.5
05	53.1	57.6	32.6	23.5	16.3	17.3	17.0
06	52.2	61.0	35.2	23.7	16.8	17.8	17.4
07	57.1	61.5	33.6	22.5	16.7	18.3	18.3
08	55.9	61.7	35.2	24.0	18.1	19.5	18.0
09	53.6	54.4	30.6	21.6	14.5	15.4	15.7
10	67.0	65.2	36.6	25.5	17.9	19.1	18.7
11	56.2	59.5	32.2	22.3	17.0	17.8	17.6
12	60.5	69.5	40.0	26.3	18.6	20.2	18.4
13	51.0	56.2	31.5	22.7	17.2	18.0	17.5
14	47.7	48.5	28.6	19.8	13.7	14.8	14.6
15	66.3	68.5	38.1	26.3	20.0	21.8	20.5
16	50.9	58.0	33.0	22.9	16.1	17.4	16.8
19	53.3	59.2	34.1	23.6	16.6	17.9	17.6
20	52.3	55.4	29.6	21.8	15.8	16.8	16.2
21	57.1	62.9	35.5	24.6	17.2	19.1	18.0
22	52.6	63.0	35.1	24.0	18.0	19.1	17.8
23	48.9	53.0	30.3	23.2	15.7	16.9	16.3
24	52.0	58.0	31.8	22.3	15.5	17.5	17.1
25	61.1	67.3	37.1	26.0	18.5	19.3	19.0
26	55.7	62.8	36.6	25.5	18.2	19.7	18.2
28	55.2	60.3	34.0	23.1	17.1	18.6	17.6
29	54.1	57.1	32.2	23.4	16.7	17.2	17.2
30	45.5	51.2	28.3	18.9	14.6	16.0	14.8
33	54.0	57.6	31.4	20.9	15.8	17.4	16.7
35	51.1	55.7	31.7	22.1	16.5	17.7	17.1
36	57.8	61.0	35.2	24.2	18.4	20.1	18.0
37	54.9	56.7	34.5	24.3	17.6	18.8	17.9
39	61.0	60.5	32.0	24.1	17.7	19.0	18.2
40	53.0	55.5	33.4	21.8	16.5	17.3	16.3

[1] Abdominal 2 girth
[2] Hip girth
[3] Thigh girth
[4] Calf girth
[5] Biceps girth (extended)
[6] Biceps girth (flexed)
[7] Forearm girth

Peak Ground Reaction Forces

Subject ID	Pvf-h[1]	Ppf-d[2]	Pvf-d[3]	Rv-d[4]	Af-d[5]
01	180	55	75	93.01	53.75
02	185	65	110	127.77	59.42
03	115	70	90	114.01	52.13
04	180	20	55	58.52	70.02
05	175	60	115	129.71	62.45
06	105	50	175	182.01	74.05
07	105	25	85	88.60	73.61
08	120	55	125	136.57	66.25
09	170	65	120	136.47	61.56
10	185	50	150	158.11	71.57
11	120	25	95	98.23	71.57
12	190	65	80	103.08	75.26
13	120	85	105	135.09	50.01
14	155	85	80	116.73	43.26
15	140	65	120	136.47	61.56
16	190	85	170	190.07	63.43
19	115	70	110	130.38	57.53
20	130	70	100	122.07	55.01
21	130	60	90	108.17	56.31
22	125	55	125	136.57	66.25
23	180	70	75	102.59	46.97
24	160	55	110	122.98	63.43
25	150	65	125	140.89	62.53
26	125	85	130	155.32	56.82
28	110	55	130	141.16	67.07
29	130	75	110	133.14	55.71
30	105	50	130	139.28	68.96
33	125	70	140	156.52	63.43
35	170	65	120	136.47	61.56
36	125	30	100	104.40	73.30
37	125	60	100	116.62	59.04
39	185	70	120	138.92	59.74
40	160	80	185	201.56	66.61

[1] Peak vertical force during jump for vertical height (% body weight).
[2] Peak propulsive force during jump for horizontal distance (% body weight).
[3] Peak vertical force during jump for horizontal distance (% body weight).
[4] Resultant vector for horizontal jump for distance (% body weight).
[5] Angle of force production during jump for horizontal distance.

Horizontal Accelerations at Takeoff (m/s/s)

ID	Foot	Shank	Thigh	Trunk	Arm	Forearm	Head
01	9.29	15.20	10.21	-2.16	1.83	0.17	3.17
02	16.37	16.33	11.31	2.28	5.44	3.68	5.20
03	34.95	14.87	-1.60	-6.53	18.89	26.45	5.46
04	20.83	24.23	12.05	-7.34	8.81	19.71	-4.05
05	25.41	21.99	11.82	-2.02	1.14	-3.83	4.47
06	-0.54	8.31	7.49	3.67	0.97	-19.33	8.23
07	29.28	10.68	-1.82	-5.83	0.59	0.71	4.95
08	14.20	19.23	12.99	-2.68	-1.97	-1.45	-0.78
09	29.25	19.35	4.44	-6.61	3.73	-0.33	5.48
10	8.05	19.23	15.50	2.21	-1.46	-1.56	3.14
11	27.86	15.33	5.19	-5.78	-1.23	5.83	0.66
12	13.20	20.53	11.66	-5.74	-6.25	-0.72	-1.38
13	22.96	24.86	16.20	-2.06	-4.83	-2.21	-3.57
14	15.70	10.23	1.91	-2.30	1.45	-5.43	5.51
15	18.96	22.50	18.49	7.96	3.01	-8.48	5.02
16	23.30	17.91	9.60	-3.33	1.36	-4.01	2.06
19	14.14	17.62	10.88	3.14	3.18	-16.38	8.55
20	15.86	19.63	11.89	-2.06	-7.21	-18.68	3.85
21	16.96	20.96	13.53	-2.68	6.48	15.16	2.88
22	26.44	20.28	8.95	-2.48	-0.52	4.42	4.23
23	11.55	17.30	13.03	-0.73	1.50	10.07	0.43
24	37.95	23.77	1.43	-4.58	15.66	15.83	9.03
25	32.82	15.58	2.23	-4.26	2.42	-4.46	4.24
26	19.78	16.40	6.94	-4.53	-2.11	-4.43	2.25
28	13.00	15.82	9.16	-2.15	8.12	21.44	1.89
29	29.36	19.00	3.97	-5.90	7.97	2.93	4.28
30	31.87	16.38	0.84	-6.78	-2.25	-14.60	2.26
33	28.01	22.06	10.44	-3.44	2.10	4.12	1.69
35	24.17	15.30	5.78	-2.68	-2.02	-7.06	7.77
36	11.69	7.71	2.48	-0.97	2.66	0.64	1.16
37	29.41	16.75	7.05	-0.82	1.98	0.29	3.18
39	22.72	14.75	5.99	-2.09	9.40	27.62	4.71
40	23.22	7.34	0.36	-1.88	3.47	5.53	2.60

Vertical Accelerations at Takeoff (m/s/s)

ID	Foot	Shank	Thigh	Trunk	Arm	Forearm	Head
01	18.88	4.65	-7.10	-12.37	-27.80	-39.08	-16.57
02	6.32	-2.59	-5.74	-5.37	-19.45	-37.67	-9.73
03	-12.24	-4.81	-3.28	-12.05	-20.74	-27.36	-18.66
04	24.97	6.05	-5.29	-9.02	-19.35	-19.17	-18.36
05	7.12	-0.92	-5.87	-9.73	-18.91	-28.58	-15.27
06	20.91	9.69	-4.47	-9.00	-18.83	-26.76	-13.61
07	-27.91	-11.76	-3.56	-11.22	-18.21	-23.80	-16.77
08	24.61	6.50	-6.21	-5.65	-18.60	-27.36	-11.76
09	3.68	1.12	-3.34	-10.02	-25.25	-44.83	-16.50
10	32.43	10.03	-5.00	-6.38	-24.55	-42.11	-12.85
11	-0.27	-2.27	-5.93	-9.06	-7.17	-3.49	-13.93
12	26.46	11.88	-3.49	-7.77	-22.61	-38.81	-15.06
13	29.19	9.02	-4.11	-5.66	-23.95	-40.49	-12.65
14	7.90	3.51	-0.94	-6.70	-12.71	-17.90	-10.28
15	21.02	6.72	-3.02	-4.50	-19.65	-39.06	-11.51
16	12.55	4.07	-4.99	-7.75	-21.13	-36.33	-15.72
19	25.78	9.63	-4.68	-8.05	-28.14	-48.96	-13.42
20	18.87	4.40	-2.49	-6.02	-25.86	-47.37	-15.70
21	11.53	0.01	-7.11	-5.13	-22.35	-40.80	-13.41
22	9.40	3.84	0.20	-7.56	-27.04	-51.20	-14.53
23	21.03	4.14	-6.97	-6.19	-17.09	-30.03	-9.92
24	-14.01	-12.21	-8.25	-10.50	-19.88	-33.27	-13.05
25	-10.74	-6.36	-4.66	-12.86	-27.90	-41.89	-17.07
26	10.75	3.29	-1.34	-6.40	-23.18	-41.93	-17.37
28	9.37	-1.44	-5.53	-5.79	-17.38	-32.39	-10.69
29	3.57	-0.55	-2.78	-7.98	-21.92	-29.00	-17.05
30	-14.97	-6.80	-3.19	-9.66	-16.81	-12.16	-15.89
33	5.44	0.53	-3.84	-5.50	-18.99	-40.16	-10.21
35	0.39	-1.66	-3.75	-7.23	-15.56	-37.27	-12.03
36	4.27	3.04	0.07	-7.35	-12.26	-11.22	-9.73
37	-0.81	-2.13	-3.16	-9.52	-18.14	-29.74	-11.61
39	1.93	-2.21	-6.28	-8.37	-22.07	-45.72	-11.56
40	-6.38	-8.35	-8.06	-9.78	-15.76	-27.02	-12.10

Resultant Accelerations at Takeoff (m/s/s)

ID	Foot	Shank	Thigh	Trunk	Arm	Forearm	Head
01	21.05	15.90	12.44	12.56	27.86	39.09	16.88
02	17.55	16.53	12.69	5.83	20.20	37.85	11.03
03	37.03	15.63	3.65	13.71	28.06	38.06	19.44
04	32.52	24.97	13.16	11.63	21.27	27.49	18.80
05	26.39	22.01	13.19	9.94	18.95	28.83	15.91
06	20.91	12.77	8.73	9.72	18.85	33.02	15.91
07	40.45	15.88	4.00	12.65	18.22	23.81	17.49
08	28.42	20.30	14.40	6.25	18.70	27.40	11.78
09	29.49	19.38	5.56	12.01	25.53	44.83	17.39
10	33.41	21.69	16.29	6.76	24.59	42.14	13.23
11	27.87	15.94	7.87	10.75	7.27	6.79	13.95
12	29.58	23.72	12.17	9.66	23.46	38.82	15.12
13	37.14	26.45	16.71	6.03	24.43	40.55	13.15
14	17.57	10.82	2.13	7.09	12.79	18.71	11.66
15	28.30	23.48	18.73	9.15	19.88	39.97	12.56
16	26.47	18.36	10.81	8.44	21.18	36.56	15.86
19	29.40	20.08	11.84	8.64	28.32	51.62	15.91
20	24.65	20.11	12.15	6.36	26.85	50.92	16.17
21	20.51	20.96	15.29	5.79	23.28	43.53	13.72
22	28.06	20.64	8.96	7.96	27.05	51.39	15.14
23	24.00	17.79	14.77	6.23	17.16	31.67	9.94
24	40.45	26.72	8.38	11.45	25.31	36.84	15.87
25	34.53	16.82	5.17	13.55	28.00	42.13	17.59
26	22.52	16.73	7.07	7.84	23.28	42.17	17.52
28	16.03	15.89	10.69	6.18	19.18	38.84	10.86
29	29.58	19.01	4.85	9.92	23.32	29.15	17.58
30	35.21	17.74	3.30	11.81	17.00	19.00	16.06
33	28.54	22.07	11.12	6.49	19.10	40.37	10.35
35	24.18	15.39	6.89	7.71	15.69	37.93	14.32
36	12.44	8.29	2.48	7.41	12.55	11.23	9.80
37	29.42	16.88	7.72	9.56	18.25	29.74	12.04
39	22.80	14.92	8.68	8.63	23.99	53.42	12.48
40	24.08	11.11	8.07	9.96	16.13	27.58	12.38

Horizontal Segment Force Contributions at Takeoff (N)

ID	Foot	Shank	Thigh	Trunk	Arm	Forearm	Head
01	18.95	72.05	94.14	-47.52	5.16	0.28	28.02
02	25.70	59.28	79.74	38.40	11.75	4.64	35.20
03	66.41	65.43	-13.68	-133.34	49.49	40.47	44.83
04	63.95	172.28	166.29	-241.78	37.27	48.68	-53.62
05	44.21	88.84	92.79	-37.83	2.75	-5.36	33.66
06	-1.06	37.73	66.06	77.25	2.62	-30.54	69.63
07	64.42	55.54	-18.64	-136.66	1.83	1.26	43.56
08	28.12	86.73	111.97	-57.62	-5.26	-2.31	-7.18
09	73.95	71.21	31.70	-112.70	8.17	-0.42	37.54
10	18.76	105.77	167.87	54.81	-4.80	-2.93	29.23
11	54.05	67.45	43.65	-121.21	-3.21	9.04	5.93
12	31.42	113.33	124.88	-146.83	-20.56	-1.38	-14.17
13	41.79	106.65	136.89	-39.84	-12.36	-3.25	-25.92
14	19.31	28.44	10.18	-30.54	2.39	-5.32	31.35
15	46.26	127.13	203.02	208.63	10.14	-16.62	52.86
16	42.87	77.73	81.98	-65.10	3.52	-5.93	15.12
19	23.05	67.84	82.47	54.45	7.31	-21.62	55.66
20	25.38	71.65	82.87	-35.82	-15.57	-24.10	28.68
21	36.46	106.48	135.44	-61.40	19.70	26.38	24.77
22	51.56	89.64	75.63	-52.28	-1.36	6.90	38.20
23	18.36	63.66	63.20	-12.45	3.29	12.89	2.95
24	70.97	103.16	12.04	-92.06	40.40	23.90	72.96
25	78.44	87.87	24.78	-108.33	8.16	-8.61	40.49
26	39.76	74.95	60.73	-98.84	-5.72	-7.13	21.04
28	27.30	76.89	86.47	-48.42	23.47	36.23	17.10
29	51.09	75.24	30.05	-111.33	18.65	4.10	34.58
30	40.79	47.83	4.67	-94.38	-3.89	-15.04	13.47
33	44.54	79.86	72.35	-59.48	4.52	5.27	12.51
35	38.91	56.15	40.58	-46.90	-4.38	-9.11	58.20
36	20.93	30.84	18.65	-19.04	6.28	0.92	10.36
37	49.11	62.31	49.35	-15.27	4.34	0.39	26.39
39	39.53	57.08	43.61	-39.71	21.43	38.39	40.69
40	33.20	23.34	2.16	-29.50	6.52	6.30	18.46

Vertical Segment Force Contributions at Takeoff (N)

ID	Foot	Shank	Thigh	Trunk	Arm	Forearm	Head
01	38.52	22.04	-65.46	-272.14	-78.40	-64.09	-146.48
02	9.92	-9.40	-40.47	-90.43	-42.01	-47.46	-65.87
03	-23.26	-21.16	-28.04	-246.06	-54.34	-41.86	-153.20
04	76.66	43.02	-73.00	-297.12	-81.85	-47.35	-243.09
05	12.39	-3.72	-46.08	-182.24	-45.57	-40.01	-114.98
06	40.98	43.99	-39.43	-189.45	-50.84	-42.28	-115.14
07	-61.40	-61.15	-36.45	-268.00	-56.63	-42.36	-147.58
08	48.73	29.32	-53.53	-121.48	-49.66	-43.50	-108.31
09	5.85	4.12	-23.84	-170.84	-55.30	-57.38	-113.03
10	75.56	55.17	-54.15	-158.22	-80.77	-79.17	-119.63
11	-0.52	-9.99	-49.87	-189.99	-18.71	-5.41	-125.09
12	62.97	65.58	-37.38	-198.76	-74.39	-74.52	-154.82
13	53.13	38.70	-34.73	-109.46	-61.31	-59.52	-91.84
14	9.72	9.76	-5.01	-88.98	-20.97	-17.54	-58.49
15	51.29	37.97	-33.16	-117.95	-66.22	-76.56	-121.20
16	23.09	17.66	-21.66	-151.51	-54.73	-53.77	-115.38
19	42.02	37.06	-35.47	-139.59	-64.72	-64.63	-87.36
20	30.19	16.06	-17.36	-104.69	-55.86	-61.11	-116.97
21	24.79	0.05	-71.17	-117.53	-67.94	-70.99	-115.33
22	18.24	16.97	1.69	-159.36	-70.84	-79.87	-131.21
23	33.44	15.24	-33.80	-105.54	-37.43	-38.44	-67.95
24	-26.20	-52.99	-69.47	-211.05	-51.29	-50.24	-105.44
25	-25.67	-35.87	-51.77	-327.03	-94.02	-80.85	-163.02
26	21.61	15.04	-11.73	-139.65	-62.82	-67.51	-162.41
28	19.68	-7.00	-52.20	-130.39	-50.23	-54.74	-96.74
29	6.21	-2.18	-21.04	-150.58	-51.29	-40.60	-137.76
30	-19.16	-19.86	-17.74	-134.47	-29.08	-12.52	-94.70
33	8.65	1.92	-26.61	-95.10	-40.83	-51.40	-75.55
35	0.63	-6.09	-26.33	-126.53	-33.77	-48.08	-90.10
36	7.64	12.16	0.53	-144.28	-28.93	-16.04	-86.89
37	-1.35	-7.92	-22.12	-173.84	-39.73	-39.55	-96.36
39	6.48	-8.55	-45.72	-159.03	-50.32	-63.55	-99.88
40	-9.12	-26.55	-48.28	-153.45	-29.63	-30.80	-85.91

Resultant Segment Force Contributions at Takeoff (N)

ID	Foot	Shank	Thigh	Trunk	Arm	Forearm	Head
01	42.94	75.37	114.70	276.32	78.57	64.11	149.22
02	27.55	60.00	89.46	98.18	43.63	47.69	74.67
03	70.36	68.77	31.21	279.96	73.52	58.23	159.60
04	99.84	177.54	181.61	383.09	89.97	67.90	248.91
05	45.92	88.92	103.54	186.18	45.70	40.36	119.80
06	40.98	57.98	77.00	204.61	50.90	52.17	134.60
07	88.99	82.58	40.96	296.52	56.66	42.38	153.91
08	56.27	91.55	124.13	134.38	49.93	43.57	108.49
09	46.89	71.32	39.70	204.77	55.91	57.38	119.12
10	77.85	119.30	176.42	167.65	80.90	79.22	123.17
11	54.07	70.14	66.19	225.43	18.97	10.52	125.27
12	70.40	130.93	130.34	247.10	77.18	74.53	155.43
13	67.59	113.47	141.20	116.62	62.54	59.61	95.47
14	21.61	30.10	11.35	94.16	21.10	18.34	66.35
15	69.05	132.66	205.66	239.82	67.00	78.34	132.26
16	48.70	79.68	92.32	165.00	54.86	54.11	116.41
19	47.92	77.31	89.75	149.82	65.14	68.14	103.57
20	39.44	73.40	84.69	110.60	58.00	65.69	120.47
21	44.10	106.48	153.05	132.65	70.77	75.74	117.99
22	54.72	91.23	75.71	167.80	70.87	80.17	136.71
23	38.16	65.47	71.63	106.22	37.58	40.53	68.09
24	75.64	115.96	70.56	230.15	65.30	55.63	128.23
25	82.53	94.86	57.44	344.58	94.36	81.31	167.98
26	45.27	76.46	61.86	171.07	63.09	67.89	163.81
28	33.66	77.23	100.91	139.17	55.43	65.64	98.28
29	51.47	75.28	36.71	187.19	54.57	40.81	142.05
30	45.07	51.80	18.35	164.40	29.41	19.57	95.72
33	45.38	79.89	77.06	112.21	41.07	51.67	76.59
35	38.93	56.48	48.37	134.93	34.04	48.93	107.27
36	22.27	33.16	18.65	145.46	29.62	16.06	87.51
37	49.13	62.79	54.04	174.57	39.97	39.55	99.93
39	39.67	57.74	63.19	163.97	54.70	74.25	107.83
40	34.43	35.33	48.34	156.27	30.32	31.44	87.90

Skinfold Measurements (mm) and Percent Body Fat

ID	Suprailiac	Thigh	Calf	Subscap.	Triceps	Biceps	% B. Fat[1]
01	5.00	12.00	7.00	5.00	8.00	4.00	19.92
02	3.00	5.50	3.00	4.00	7.50	3.50	17.18
03	3.50	7.50	4.50	4.50	8.00	3.00	18.11
04	5.00	13.00	8.00	6.00	8.00	4.00	19.96
05	3.00	12.00	8.00	3.50	10.00	5.50	22.30
06	4.50	12.00	8.50	4.00	8.50	4.50	20.92
07	13.00	10.50	8.00	4.50	10.50	4.00	23.98
08	3.50	12.00	7.50	5.50	10.50	4.50	25.59
09	3.00	12.00	8.00	5.00	9.00	3.00	22.85
10	4.00	11.00	6.00	5.00	6.50	4.50	17.04
11	4.50	9.50	7.00	5.50	10.50	4.50	23.51
12	5.00	17.00	10.00	5.00	12.00	5.00	25.42
13	2.00	7.50	7.00	3.50	7.00	3.00	18.12
14	3.00	8.00	4.00	4.00	7.50	3.00	21.87
15	8.00	16.00	14.00	10.00	14.50	6.50	30.29
16	3.00	7.00	6.00	4.50	9.00	4.00	19.86
19	3.00	6.50	6.50	4.00	8.00	3.50	18.47
20	3.50	9.00	6.00	4.00	8.00	4.50	19.67
21	4.00	9.50	5.50	4.50	8.00	3.50	21.61
22	3.50	14.00	10.00	6.00	12.00	5.00	27.40
23	2.50	8.50	8.00	4.00	8.00	3.00	20.03
24	2.00	9.00	6.50	4.00	6.50	3.00	17.59
25	4.00	9.50	7.00	6.00	8.00	4.50	18.94
26	3.00	13.00	7.00	5.00	9.50	4.00	21.92
28	3.50	6.50	5.50	4.00	6.00	2.50	16.58
29	3.50	9.50	7.00	5.50	11.00	4.00	23.85
30	4.50	11.00	7.50	4.00	8.50	5.00	21.02
33	7.00	13.00	8.00	5.50	10.50	5.50	25.96
35	3.00	8.00	9.00	5.50	9.00	3.00	22.36
36	6.50	18.50	14.50	6.50	12.50	7.50	30.11
37	5.00	17.00	11.00	6.00	8.00	5.00	23.63
39	8.00	22.00	12.00	7.00	16.00	6.00	32.63
40	5.00	25.00	17.00	5.00	14.00	10.00	29.56

[1] Percent body fat equations taken from Mukherhee, D., and Roche, A. F. (1984). The estimation of percent body fat, body density and total body fat by maximum R^2 regression equations. Human Biology. 56:79-109.

Equations:

Girls: 17.19 - 0.74(Age) + 1.02(Triceps) + 0.32(Midaxillary)

Boys: 12.66 - 0.84(Age) + 1.10(Triceps) + 0.53(Calf)

Center of Gravity Relative to Toes at Takeoff and Landing & Angle
Center of Gravity Forms With Toes at Takeoff

ID	X-tt[1]	X-cgt[2]	H-dt[3]	X-hl[4]	X-cgl[5]	H-dl[6]	Y-cgt[7]	A-t[8]
01	1.22	1.17	0.29	1.17	1.63	0.46	0.59	63.82
02	0.88	0.92	0.04	0.84	1.51	0.67	0.49	85.33
03	1.35	1.33	-0.02	1.36	1.77	0.41	0.58	91.97
04	1.32	1.33	0.01	1.29	1.83	0.54	0.53	88.92
05	0.92	0.92	0.00	0.87	1.30	0.43	0.52	90.00
06	1.04	1.01	-0.03	0.97	1.54	0.57	0.53	93.24
07	1.11	1.25	0.14	1.13	1.59	0.46	0.81	80.19
08	1.11	1.16	0.05	1.07	1.73	0.66	0.48	84.05
09	1.34	1.29	-0.05	1.34	1.75	0.41	0.49	95.83
10	0.85	0.94	0.09	0.78	1.76	0.98	0.54	80.54
11	1.17	1.13	-0.04	1.17	1.46	0.29	0.52	94.40
12	1.10	1.14	0.04	1.04	1.67	0.63	0.54	85.76
13	0.83	0.99	0.16	0.82	1.61	0.79	0.49	71.92
14	0.84	0.77	-0.07	0.81	1.03	0.22	0.34	101.63
15	0.86	0.93	0.07	0.78	1.52	0.74	0.53	82.48
16	0.86	0.97	0.11	0.86	1.46	0.60	0.50	77.59
19	0.95	0.97	0.02	0.88	1.54	0.66	0.53	87.84
20	0.89	0.97	0.08	0.84	1.58	0.74	0.46	80.13
21	0.91	1.01	0.10	0.89	1.77	0.88	0.57	80.05
22	0.88	0.90	0.02	0.85	1.37	0.52	0.53	87.84
23	0.90	0.97	0.09	0.90	1.54	0.64	0.48	79.38
24	0.91	1.08	0.17	0.97	1.61	0.64	0.65	75.34
25	0.90	1.02	0.12	0.92	1.54	0.62	0.63	79.22
26	0.92	0.99	0.07	0.91	1.45	0.54	0.46	81.35
28	0.98	0.96	-0.02	0.99	1.58	0.59	0.57	92.01
29	0.96	0.75	-0.21	1.00	1.55	0.55	0.34	121.70
30	0.90	0.98	0.08	0.92	1.31	0.39	0.46	80.13
33	0.88	0.93	0.05	0.89	1.27	0.38	0.41	83.05
35	0.92	0.88	-0.04	0.89	1.27	0.38	0.42	95.44
36	0.95	0.81	-0.14	0.90	0.99	0.09	0.39	109.75
37	0.89	0.88	-0.01	0.92	1.26	0.34	0.40	91.43
39	0.68	0.70	0.02	0.62	0.99	0.37	0.48	87.61
40	0.77	0.70	-0.07	0.68	0.92	0.24	0.54	97.39

[1] X-coordinate of toes at takeoff.
[2] X-coordinate of center of gravity of body at takeoff.
[3] Horizontal distance between toes and center of gravity at takeoff (takeoff gain).
[4] X-coordinate of heels at landing.
[5] X-coordinate of center of gravity of body at landing.
[6] Horizontal distance between heels and center of gravity at landing (landing gain).
[7] Y-coordinate of center of gravity of body at takeoff.
[8] Angle formed between center of gravity of body and toes at takeoff (lean angle).

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