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A biomechanical analysis of developmental patterns in childrens running.

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A BIOMECHANICAL ANALYSIS OF DEVELOPMENTAL PATTERNS IN CHILDRENS RUNNING

By

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ABSTRACT

The purpose of the research was to determine the magnitude of temporal and kinematic changes which occur during the development of the running movement pattern in children. Various biomechanical variables of the right running stride were analyzed from sixty-three male subjects, with an age range of six to twelve years old inclusive. The results for the fifteen variables were analyzed separately by a one way randomized block design analysis of variance and the Scheffe method of post hoc analysis. The measured parameters were subsequently used to develop a profile of the development of the running movement pattern of children and to describe the relationship between running performance and a combination of temporal and kinematic variables.

The research revealed that the temporal variables showed no statistically significant differences in the seven different age groups analyzed. The kinematic data measured in this study produced three statistically significant differences in the magnitude of technique changes analyzed. Horizontal velocity, stride length and relative foot velocity were the variables that produced statistically significant differences at less than the .05 level. Various angular data associated with the technique changes in the developmental patterns of childrens running performance were investigated. The results for these variables produced no apparent developing trends across the age groups analyzed. It was concluded that by age six, the fundamental male running pattern has been developed and that the only significant changes that occur up to age twelve are in strength and power.

DEDICATION

To Albert and Jessie, my parents.

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CHAPTER 1

INTRODUCTION

A majority of physical activities require the rapid movement of the body from one place to another. Thus running, in its various forms, is a basic skill essential to the performance of a variety of physical activities. The activity, running, is a rapid form of human locomotion characterized by brief projections of the body over the ground alternately by each leg.

> Running is really a series of smooth coordinated jumps during which the body weight is borne on one foot, becomes airborne, is then carried on the opposite foot and again becomes airborne.
> (Wickstrom, 1977, p.37)

There are basically two types of running: accelerated and constant velocity. In accelerated running an athlete continually increases horizontal velocity from stride to stride, while in constant velocity running, the average horizontal velocity from stride to stride remains constant. It is important to make the distinction between these two types of running, because the majority of biomechanical research on running has analyzed the constant velocity variety.

One of the primary objectives of research in biomechanics of sport is to identify movement patterns for an activity which are associated with better performances.

> How can they determine which features of a champions technique contributes to the high quality of his performance and thus are possibly worth copying, and which faults are limiting that performance? The answer to this

> question lies with the science of BIOMECHANICS for it provides the basis, the only sound logical basis upon which to evaluate the techniques brought to our attention by champions. (Hay, 1973, p.4)

Skilled adult performance of a fundamental movement pattern can be defined as the mature stage of this activity. Detailed biomechanical analysis of the movement provides information against which the developmental level of a child can be compared. The purpose of using detailed information about the mature stage in the study of child's movement is not to force the child to conform to this pattern; in a biomechanical sense, it is to provide a background against which the childs' movement progress can be evaluated.

There are three basic types of quantitative sports skill analysis: temporal, kinematic and kinetic. The first is concerned with the timing or sequential order of various aspects of the performance. Kinematic investigation concentrates on the description of motion without regard for the forces producing it. Kinetic studies are concerned with the determination of causes of motion.

Practical biomechanical research may be useful in improving the technique levels of young runners and in aiding to facilitate proper development of running patterns. It is therefore desireable that quantitative study of the activity be undertaken. This study proposed the examination of temporal and kinematic parameters of childrens performance of the running stride. Included in the group of parameters which were considered to be important measures of a runner's skill

(Dillman 1971, 1975, Beck 1966, Dyson 1977) are the following: horizontal velocity, stride lengths and frequencies, time of support and non-support phases, the component percentages of the stride and the positions of various body segments throughout the stride.

In most studies, running velocity is the dependent variable and performance parameters are analyzed with respect to a given velocity. Consequently, performance data is obtained at various discrete speeds along the continuum of running velocities and then combined to provide a total view of how man runs at various rates. The selection of temporal and kinematic parameters for investigation in a biomechanical study is usually based upon the importance of these factors in relation to the significance of their influence upon the performance of the activity.

> Almost any sports skill can be divided into similar components which have practical significance when they are related to the performance. (Miller and Nelson, 1973, p.40)

STATEMENT OF THE PROBLEM

The purpose of the study was to determine the magnitude of technique changes which occur during the development of the running movement pattern in children. More specifically, the study included assessment of changes in the following temporal and kinematic variables which occur in the maximum velocity running patterns of boys between the ages six and twelve:

1) horizontal velocity
2) stride rate
3) stride length

4) time of single support

5) time of flight

6) time of stride

7) percentage of single support

8) percentage of flight

9) relative foot velocity at the point of ground contact

10) hip angle at take off

11) hip angle at mid-flight

12) hip angle at touch down

13) hip angle at mid-support

14) ankle angle at take off

15) knee angle at take off

The variables that were analyzed, with expected change of magnitude and the accompanying rationale for this predicted change are indicated below:

INCREASE IN MAGNITUDE

Horizontal velocity, stride length, stride rate: When horizontal velocity increases, it is accompained by an increase in either stride length or stride rate or both, depending upon the individual (Hay 1973, Dyson 1977). As the child matures physically, extra strength is gained, thus the individual will create more power, which is reflected in increases of these variables.

Time of flight and percentage of flight: As mentioned above, with increased power, the runner will generate a greater force at take off, thus a longer flight phase, and a greater percentage of flight are to be expected.

Relative foot velocity: Both Fenn (1930) and Dillman (1971) have mentioned the advantages of the direction of foot placement at touch down. Thus the runner who can have the touch down foot moving in the opposite direction to the body's motion is working more efficiently. It is anticipated that efficiency increases as the movement pattern develops and it is expected that relative foot velocity will increase with age.

Knee and ankle angle at take off: The greater the extension of the leg at take off the greater the work that can be completed with the result being more power to propel the body forward. These two angles will reflect the amount of work that the runner is doing during propulsion and should increase with age.

DECREASE IN MAGNITUDE

Time of single support and percentage of single support: As previously mentioned, time of flight should increase with age and thus there must be a subsequent decrease in time of single support and percentage of single support.

Time of stride: With stride rate increasing, the time to complete a stride will subsequently decrease.

UNCERTAIN TO CHANGE IN MAGNITUDE

A reasonable prediction as to the direction of change in the following variables cannot be made due to either conflicting results in the review of literature or insufficient research in the area: hip angles at take off, mid-flight, touch down, and mid-support.

LIMITATIONS

The limitations of this study fell within two main categories: cinematographical limitations and potential theoretical limitations.

The cinematographical limitations were associated with the reliability and validity of taking real life measures from a projected image. Most of the sources of experimental error were minimized by following stringent experimental and measurement procedures. There was, however, a degree of error which results from the distortion of the image and from measurement of the displacement - time data.

Film records the movement in one plane. Therefore if there is movement outside this plane, it is not quantifiable and may cause distortion, if the distance between camera and subject is not great. Due to the nature of the running stride, most movement occurs in one plane.

> The optimum position of the feet in running is one in which the inner borders fall approximately along a single straight line.
> (Dyson, 1977, p.136)

The motion of the arms and legs are nearly parallel to the direction of motion and there is some rotation of the hips and shoulders. Also, there is a slight lateral movement of the body to ensure that the balance of the runner is maintained. An attempt was made to minimize error due to these factors by filming with a large camera - subject distance, using a telephoto lens.

The farther the subject moves away from the center of the filming area, the greater the distortion in image size. This problem was averted by analyzing only the right stride that was completed nearest the center of the filming area.

There is some question as to the methods of obtaining real life measures from film and applying them to the principles of mechanics. This is clearly related to the assumption that rigid body segments are similar in nature to the structures in engineering systems. The assumption of a body segment as a straight line is not an entirely adequate representation for the following reasons. First, the actual axis of rotation may not correspond with the surface landmarks and may change during movement. Second, due to the rapid acceleration or deceleration of the segment, the volume and density might vary, due to movement and distortion of body tissue. Even with these limitations, estimates of lengths, masses and centers of mass are necessary in order to quantify human movement. Based on previous use of segmental models (Dillman 1970) it appears to be valid in biomechanical investigations to use the mechanical representation of the body as a series of rigid, connected segments with calculated centers of mass, length, density and volume.

The potential theoretical limitations of the study were related to basic assumption that were made. These assumptions were: first, that performance depends mainly upon the mechanical factors involved. Second, the parameters selected are important components of the skill, and that differences which occur across age groups are important to the achievement of the objectives of the running stride. Based on previous research (Dillman 1970, 1971) it appears that these assumptions are valid.

DEFINITIONS

The following were the definitions of the major terms that were used throughout the study.

Horizontal velocity: refers to the speed in a given direction, in which the runner was moving. An equation of running can be derived which relates two movement parameters or kinematic factors to the objective of running - horizontal velocity. The derivation of this equation is as follows: H.V. = H.D. x S.R., where H.V. is the average horizontal velocity of the body over one stride, H.D. is the horizontal displacement of the body over one stride, and S.R. is the rate of striding.

Running cycle: is the period of time from the occurrence of one event until that same event is repeated. For the purpose of this study, a cycle consisted of the take off of one foot to the subsequent take off of the same foot.

Running stride: is the interval of time from the take off of one foot until the take off of the opposite foot. Thus the right stride is the time from take off of right foot to the subsequent take off of the left foot.

Stride length: is the distance between the take off point of one foot and the subsequent take off of the other foot.

Stride rate: is the reciprocal of the time of stride and denotes the number of strides taken each second.

Center of gravity: is the point at which the mass of the entire body may be theoretically represented. It is calculated by using the relative weights and locations of the centers of mass of the respective body segments.

Flight phase: is when the body moves forward over the running surface due to the momentum given to it by the take off leg. During this period of time the body is not in contact with the ground.

Support phase: is when the body continues to move forward rotating about the supporting leg. During this period only one foot is in contact with the ground. This also can be referred to as single support.

Recovery phase: is the action of bringing the leg forward through the air to a position in front of the body, ready for the subsequent support phase.

Touch down: occurs when the recovery leg comes into contact with the ground, enabling the body to again rotate forward over the supporting leg.

Take off: refers to the time when the foot of the runner leaves the ground. This occurs after the body of the runner has rotated forward over the supporting leg.

Mid-flight: after the take off, the body moves in a parabolic flight path, mid-flight occurs halfway between take off and the subsequent touch down.

Mid-support: after touch down, the body rotates over the support foot, mid-support occurs halfway between touch down and the next take off.

ASSUMPTIONS

The following were the assumptions basic to any study in biomechanical research, employing cinematographical techniques:

1) The optimal performance objective in this study was a high

horizontal velocity and subsequently a lower time over a given distance.

2) The average velocity for a stride is calculated by using the running equation (H.V. = S.L. x S.R.) is approximately equal to the velocity determined by measuring the horizontal displacement of the center of gravity during the stride and dividing by the stride time. Therefore, it was assumed that stride length is an accurate representation of the horizontal displacement of the center of gravity during a stride.

3) Each of the body segments was assumed to be a rigid body. The effect of tissue deformation and fluid movement on mass distribution and inertia were considered negligible.

4) The joint connections between the segments were considered pinned. Actually the human joint connections permit a small displacement between adjacent bones, however, the motion was considered negligible when compared to the total limb movement.

5) The joints were assumed to have negligible friction.

CHAPTER II

REVIEW OF LITERATURE

The intent of this study was to quantify technique changes which occur during the development of the running movement pattern in children. The review of literature undertaken prior to the initiation of the study fell into two main categories. Broadly defined, these included: mechanics of running, and studies on childrens running patterns.

MECHANICS OF RUNNING

Most forms of locomotion are associated with bipedalism. It is important to realize also, that all translatory motion of the body is produced by a combination of coordinated rotations of body segments. Running is characterized by the following components: touch down, mid-support, and take off points during the stride, and by follow through, forward swing, and foot descent phases during recovery.

Luhtanen and Komi (1978) emphasized the concept of two phases of work by the ground contact leg in the running stride. The negative phase was assumed to begin at the first instance of ground contact, lasting until the foot was directly beneath the body's center of gravity. This phase was termed negative work based on the understanding that the extensor muscles of ground contact leg were contracting eccentrically and thus performing negative work. The positive phase, consequently was assumed to be made up of the latter portion of contact time, from when the foot was directly below the body's center of gravity until the instance of take off. The muscles of the leg in this phase were determined to be acting concentrically, thus the work being performed was thought to be positive.

Research into the kinematic patterns of the running stride has revealed that, a runner loses some momentum when his foot strikes the ground (Fenn 1930). Fenn spoke of this in terms of efficiency of running, with the more accomplished runners placing their feet beneath the center of gravity of the body, thereby decreasing the amount of deceleration.

> A simple force diagram will reveal that the farther ahead of the body the foot strikes the ground, the more acute the angle and the greater deceleration from ground resistance.
> (Slocum and Bowerman,1962,p.38)

Fenn (1930) remarked that it is conceiveable that a good sprinter might be able to run without retarding his speed, by getting his foot directly under his center of gravity. The placement of the foot at contact is an important criteria that distinguishes a mature running pattern, but is not as important as the direction in which the foot is moving at the point of ground contact. Ideally, the foot should be moving in a backwards direction relative to the body, thus creating negligible deceleration of the total body throughout the contact phase of the running stride. Dillman (1971) has verified and extended this concept, of the touch down foot moving in a backward direction prior to ground contact, he states:

> During the later stages of recovery, the leg was stopped, reversed, and moved backward in relation to the body prior to touch down.
> (Dillman, 1971, p.162)

Research into the kinematic patterns of the leg movement during recovery (Dyson 1977, Elliot 1977, Sinning and Forsyth

1970) has revealed that, as the thigh is moved forward rapidly, the lower leg is flexed acutely behind the thigh. This action reduces the moment of inertia of the leg about the hip joint, thus facilitating forward recovery. The elevation of the thigh increases with increased speed and the better runners tend to have greater hip flexion.

Dillman (1974) has shown, through a relative velocity analysis of the leg segments during recovery, that the rotation of the thigh about the hip is primarily responsible for moving the leg forward until midway through the support phase on the opposite leg. The thigh reaches its maximum forward position usually at the termination of the support phase by the opposite foot. As the speed of running increases, the elevation of the thigh or knee joint in front of the body becomes greater. In addition there is a tendency for highly skilled runners to have a greater lifting of the thigh, with a greater maximum propulsion resulting in the knee joint of the swing leg in a position in front of the body, while the untrained tend to keep the joint near the support leg.

Deshon and Nelson (1964) analyzed the mechanics of sprint running to determine the relationship of velocity of running to three variables. These variables included the angle to which the leg is raised in front of the body, the length of two strides, and the angle the leg makes with the ground at the point of touch down. Statistically significant inter-correlations were found to exist for all variables except the mean angles of leg lift and leg touch down.

Studies in which the periods of support and non-support were investigated have generally indicated that as the velocity increases, the period of support becomes shorter while the period of non-support becomes larger (Dittmer 1962, Hopper 1964, Copper and Glassow 1968). Buchanan (1971) and Kurakin (1972) reported a curvilinear relationship between time of flight and running velocity. They reported that time of non-support initially increases with velocity and subsequently decreases when higher velocities are attained. The research conducted on time of non-support generally indicates no significant changes in this parameter, as velocity is increased (Kurakin 1972).

The majority of research completed on the recovery of the leg and foot during running has been devoted to an analysis of the segmental angular displacement patterns and positions of the leg segments at certain times during the recovery cycle. Examples of this research can be found in studies by Fenn (1930), Deshon and Nelson (1964), and Dillman (1971).

CHILDRENS RUNNING PATTERNS

The relationship between limb length and stride rate might lead to the assumption that young children would use extremely fast stride rates in their running, and in some instances they do (Radford and Upton 1976). The toppling gait of the very young child may be performed at about two steps per second, and the running gait of older children is often faster (May and Davis 1974). The complex interplay of parameters that produce optimal performance in childrens running needs to be examined further in order to enhance the basic knowledge of the development of childrens running patterns. Performance parameters are considered to be of significance in the analysis of the running stride technique.

> It is apparent that if a runner is to improve his speed, he must bring about an increase in one parameter (either his stride length or his stride frequency) without causing the other to be reduced a comparable amount.
> (Hay, 1973, p.397)

By the age of five, most children have developed reasonably acceptable running form and understand what it means to run fast (Wickstrom 1977). The majority of research into the developmental patterns of childrens running has examined children after the age of five.

Clouse's (1959) investigation examined the running patterns of six carefully selected preschool boys, ages one and a half to five and a half years. For this representative group, running speed increased over the age range and was accompained by an increase in the length of the stride and longer non-support periods.

Dittmer's (1962) subjects were two good and two poor runners selected at age six and studied yearly through age ten. With each successive year, there was an increase in speed; in the length of stride; in the amount of time in the non-support phase of the stride; in the velocity of the supporting leg; and in the flexion of the knee of the swinging leg during recovery and at contact. These trends are consistnet with those reported by Clouse (1959).

Fortney (1963) followed the development of the action of the swinging leg in the running patterns of twelve boys over a period of five years. Four boys who were above average, four who were average, and four who were below average in running speed in grade two were the subjects in this longitudinal study which continued through grade six. Over the five year period there was a tendency to increase the height of the leading thigh at the beginning of the non-support phase of the stride. A second trend over the period was the progressive amount of flexion of the lower leg, with the heel being brought closer to the buttocks on the forward leg swing. These same trends were observed in the younger runners studied by Clouse (1959) and in the girls studied by Dittmer (1962).

The path of the center of gravity during the running stride was the concern of the last of these important studies of the developmental form (Beck 1966). The running form of twelve boys who had been carefully identified as good runners were studied for two consecutive years. Four boys in grades one, three, and five were studied and then restudied after they had moved on respectively to grades two, four, and six. Beck (1966) found that generally the center of gravity of the body moved upward briefly following take off. Then it began to move in a downward path and continued in this direction until after the support foot made contact and began its propulsive effort. The center of gravity of all runners had an undulating, wavelike path. With increased age and speed of running, the wavelike movement became relatively flatter, with the horizontal component increasing more than the vertical component. The boys simply became less bouncy in their running stride as they advanced in age and increased in speed.

SUMMARY OF LITERATURE REVIEW

A review of the literature related to the mechanics of running, revealed that several studies have investigated numerous kinematic parameters directly related to running performance. Most notably, several studies have dealt with limb action during the recovery phase of running. Kinetic investigations, more limited in number than kinematic, have dealt with the forces that produce and modify specific movement components of running. The subjects studied in both areas, consisted mainly of adult, male college students. Thus indicating the lack of research in the development of the running movement pattern in children.

Literature related to childrens running patterns has fallen into two main categories; first, the majority of the research reviewed dealt with fundamental patterns from a longitudinal perspective. Second, several researchers analyzed a few subjects, and studied a small number of designated performance parameters. This limited research into the mechanics of the running movement pattern in children has left many questions unanswered with regards to the understanding of the mechanical factors involved in the development of the running stride.

The need for future research into the temporal components of the running stride is evident. Most notably times of single support and flight, with their accompanying percentages of the total stride time, and how these variables change in magnitude requires further examination. The relationship between the kinematic variables of stride length and stride rate, and the significance of each in the attainment of maximal running velocity has not been examined thoroughly and warrant further investigation.

The ability of the runner to reduce the retarding ground reaction forces that he encounters upon contact with the ground, is a variable that research concerned with the development of the running movement pattern in children has not examined. Studies which have examined this variable, dealt with elite adult runners, and found that this is one distinguishing factor which is a significant contributor to the efficient execution of the running stride because it allows propulsive forces to be applied for a longer period of time. Therefore, examination of the relative foot velocity at the point of ground contact, will provide useful information upon which the subjects' performance of the maximal running velocity can be analyzed.

Some segmental angular data, associated mainly with the recovery leg during the running stride has been generated for the running patterns of children. However, no research into the angles that are formed by the lower limbs, especially the ankle and knee angles at the point of take off, has been conducted on the patterns of childrens running. Maximal hip extension during the completion of the stride, is an important aspect of technique in the maximal velocity patterns of runners because it reflects an increase in the work done during support.

At this time, it appears that no research has been conducted on the magnitude of hip extension in the development of running movement patterns in children.

The different phases of the stride in which there is contact with the ground (take off, touch down, mid-support) all have vertical and horizontal reaction forces being applied through the point of ground contact. These tend to cause rotation of the body, which may inhibit the performance of the runner if they are applied in a backward direction. This further indicates a need for research into this area, to determine the range of hip extension that is benefical for the completion of the running stride.

In conclusion, the development of the mechanics of the running movement pattern in children have been investigated to a certain extent. Further research, however, to clarify the remaining questions about the developmental changes in the running movement patterns of children is warranted.

CHAPTER III

METHODS

This study involved the measurement of selected parameters of childrens running performance, through the use of high speed cinematography. The measured parameters were subsequently used to develop a profile of the development of the running movement pattern of children and to describe the relationship between running performance and a combination of temporal and kinematic variables.

SUBJECTS

The sample size consisted of sixty-three male runners from seven different age groups, six to twelve inclusive. The subjects were choosen from the primary school system of Windsor. The structural characteristics of the subjects are described in table form in the appendix. It was assumed that subject performances would be normally distributed within each age group.

PRELIMINARY MEASURES

Prior to filming, steps were taken to prepare the subjects and preliminary measurements were made. This was undertaken to both familiarize the subjects with the task requirements and to decrease the possibility of error in subsequent analysis. There was no formal subject preparation, such as joint marking, since typical running attire (gym shorts, tee shirt and gym shoes) are brief in nature, thus providing a clear view of body segments and joints. The age, height and weight of each subject were recorded prior to filming.

FILMING AREA

From the review of literature, and subjective evaluation of the requirements of the study, the filming area was set approximately five meters long and one meter wide. An area of this size ensured the occurence of at least three complete running strides in each filmed segment.

The subjects ran approximately twenty meters before entering the filming area, in order to attain maximum velocity prior to filming. The runners were instructed to run at their maximum controlled velocity and to retain this pace throughout the photographic area. The camera started prior to each subject entering the filming area, thus allowing time for the desired film speed to be attained.

To facilitate identification of subjects, numbered placards were placed on either side of the filming area. A vertical line behind the filming area, and reference objects were also used to ensure that each successive frame of film was locked into the same position on the projection screen during film analysis.

FILMING PROCEDURE

Each trial was filmed with a Locam sixteen millemeter camera, loaded with Kodak 4-X film and set to operate at one hundred frames per second. A side view of each performance was recorded.

The camera was placed seven and a half meters from the filming area with the optical axis of the twenty-five millemeter lens perpendicular to the plane of movement. It was set at a height of approximately one meter above the ground and in an upright position. Thus, the filming area was bisected by the optical axis of the camera lens. Placement of the camera in this manner allowed for the filming of an adequate area and provided a suitable image size on the film for accurate measurement of the temporal and kinematic parameters that were analyzed.

In order to make a precise measure of actual film speed, a quartz crystal impulse generator was used to fire the light emitting diodes inside the camera. The generator was set at one hundred impulses per second and thus, one hundred dots were exposed on the film for each second that the camera was operating. Using these dots as a reference, film speed was calculated in frames per second.

Prior to filming the subjects, and following each change of film during testing, a reference stick was filmed in the plane of motion by the camera. The projected image of the stick of known length was used during film analysis to determine conversion factors for converting film measurements to real life size and distance.

FILM ANALYSIS

Film analysis was facilitated by the use of a Numonics electronic graphic calculator, and a Vanguard M-16C projector head. Throughout the film analysis procedure, the coordinate system of the Numonics analyzer was used to represent positional or segmental points in both X and Y coordinates. Prior to the extraction of data from the film, the following calculations were computed: a distance multiplier, frame rate, and time per frame.

DISTANCE MULTIPLIER

To determine a multiplier to convert film measurement to life size, the projected image size of the meter stick filmed in the plane of motion was measured in Numonics units. Since the real life size was known (one meter) the multiplier was determined by using the following formula:

$$\text{Multiplier} = \frac{\text{1m}}{\text{Numonics Units}}$$

TIMING PARAMETERS

The frame rate and subsequent time per frame were determined through the use of light exposure dots placed on the film by the internal timing lights and the pulse generator. Since these exposure dots occur at accurate .01 second intervals, they were used to determine the elapsed film speed, and subsequently the time per frame:

$$\text{Film Speed} = \frac{\text{Frames}}{\text{Exposure Dots}} \times 100 \text{ Exposure Dots/second}$$

Time per frame was then calculated by the following formula:

$$\text{Time per Frame} = \frac{\text{One Second}}{\text{Film Speed}}$$

CALCULATION OF LINEAR DISPLACEMENT

Displacement data was calculated by using a Numonics graphic analyzer. From the projected image, the operator was able to determine the X and Y coordinates at a desired point, producing an accurate two dimensional location measured to the nearest analyzer unit. Linear displacement was then calculated between two desired points from the following equation:

$$\text{Linear Displacement} = (X_2 - X_1) \times \text{Multiplier}$$

CALCULATION OF ANGLES

All angular measurements were made in two stages. Initially data points from the film were recorded. Then, these data points, through the use of trigonometric formulae, were converted to actual angular measurements. In cases where three data points were recorded, the cosine rule was applied. When two data points were used, the tangent rule was used to determine the angle.

PARAMETERS MEASURED FROM FILM

The following is the list of temporal and kinematic variables that were studied from the film.

Stride length: The stride length analyzed was choosen from the right stride performed nearest the center of the filming area. The horizontal distance between subsequent take off points of alternate feet, represented the stride length. The projected distance was converted to real life distance via the multiplier.

$$\text{Stride length} = (X_1 - X_2) \times \text{Multiplier}$$

Stride rate: Prior to determing stride rate, the time taken for the stride was calculated by multiplying the number of frames exposed during the stride by the time per frame. The reciprocal of the time of stride was calculated and termed stride rate.

$$\text{Stride rate} = \frac{\text{One Stride}}{\text{Time of Stride}}$$

Horizontal Velocity: Horizontal velocity for the analyzed stride was calculated from the multiplication of stride length, and stride rate. Thus, the equation for horizontal velocity was:

Horizontal velocity = Stride length X Stride rate

Time of Single Support: The time during which the body was supported by one leg was determined by multiplying the number of frames of single support by the time per frame (TPF).

Time of Single Support = Frames of Single Support X TPF

Percentage of Single Support: The percentage of time that the body is supported by one leg, was calculated from the ratio of time of single support over time of stride, multiplied by one hundred per cent.

$$\text{\% Single Support} = \frac{\text{Time of Single Support}}{\text{Time of Stride}} \times 100\%$$

Time of Flight: The time during which the body was not in contact with the ground was determined by multiplying the number of frames of flight by the time per frame (TPF).

Time of Flight = Frames of Flight X TPF

Percentage of Flight: The percentage of time that the body is not in contact with the ground, was calculated from the ratio of time of flight over time of stride, multiplied by one hundred per cent.

$$\text{\% Flight} = \frac{\text{Time of Flight}}{\text{Time of Stride}} \times 100\%$$

Time of Stride: This parameter was assumed to be the time taken to complete one stride. The time of stride value is the reciprocal of stride rate.

$$\text{Time of Stride} = \frac{1}{\text{Stride Rate}}$$

Relative Foot Velocity: From Fenn's (1930), and Dillman's (1971) studies on the position and direction of the foot at touch down, this parameter was considered important in the technique of running. Relative foot velocity was quantified by measuring the linear displacement of both hip and toe of the touch down leg, prior to and at the point of ground contact, then subtracting the former from the latter.

$$RFV = \frac{(Xhip_2 - Xhip_1)}{\Delta Time} X \text{ Multiplier} - \frac{(Xtoe_2 - Xtoe_1)}{\Delta Time} X \text{ Multiplier}$$

Hip Flexion Angles: The angles of hip flexion at take off, mid-flight, touch down, and mid-support were measured using the cosine rule of trigonometry, and the coordinate points of selected skeletal landmarks on the body. The angles were represented by the angles formed between the trunk and thigh midlines, during the four particular phases of the movement. The trunk midline is the line formed between the center of the ear and the greater trochanter of the femur. The thigh midline is represented by the line formed between the greater trochanter of the femur and the lateral tuberosity of the tibia.

Knee Flexion Angle: A method similar to that used for hip flexion angles was used to determine the angles of flexion of the knee joint at take off. The angle which was measured was formed between the midline of the thigh and the shank midline. The thigh midline has been described previously. The midline of the shank was represented by the line formed between the lateral tuberosity of the tibia, and the lateral malleolus of the fibula.

Ankle Flexion Angle: The previously mentioned method was also used to measure the angle of ankle flexion at take off. The midline of the shank has been described previously, the foot was represented by the line formed between the lateral malleolus of the fibula and the head of the first phalange. The angle that these two segments formed at take off was measured.

DATA ANALYSIS

The data analysis was conducted in three phases: attainment of X and Y coordinates from the film, Apple micro-computer analysis, and statistical analysis of data.

Coordinates From Film: The Numonics electronic graphics calculator represented the points being analyzed in a X and Y coordinate system. The points were then entered into the computer which determined the selected parameters.

Micro-Computer Program: The coordinate points were fed into an Apple micro-computer, with a predetermined program, which then quantified the parameters in question. The results were recorded by an online printer, and visually represented on an adjacent television screen. The results were then subjected to statistical analysis.

Statistical Analysis: The statistical analysis that was performed on the obtained data was a one way randomized block design analysis of variance. The primary purpose of this analysis was to test the null hypothesis that there are no statistically significant differences in the running mechanics of children between the ages of six and twelve. Thus, for each of the following variables:

1) horizontal velocity

2) stride rate

3) stride length

4) time of single support

5) time of flight

6) time of stride

7) percentage of single support

8) percentage of flight

9) relative foot velocity at the point of touch down

10) hip angle at take off

11) hip angle at mid-flight

12) hip angle at touch down

13) hip angle at mid-support

14) ankle angle at take off

15) knee angle at take off

an analysis of variance was performed to distinguish if any significant differences existed between the seven age groups tested.

If a significant difference did occur, the Scheffé method of post hoc analysis was performed. In general, this method can be applied to all comparisons of all means after an analysis of variance.

IMPLICATIONS OF MATURATION

The assessment of developmental age is a useful means of comparing a given individual to a standard population. It may be used for any anthropometric, physiologic, or psychologic characteristic which varies predictably with chronologic age, and for which there are acceptable standards for children at various ages. Stuart and Meredith (1946) found that the most reliable measures for the prediction of chronologic age of children were the height and weight standards they determined from their experiment. Cheek (1968) added to this by explaining that height has a higher correlation value (.92) than does weight (.89) in the estimation of chronologic age.

The body height of individuals is an accurate measure in the determination of chronologic age levels. Thus a correlation between body height and technique variables was undertaken. The variables that were correlated with height were the following: horizontal velocity, stride length, time of flight, and relative foot velocity.

CHAPTER IV

RESULTS AND DISCUSSION

The major focus of the study was the determination of temporal and kinematic changes which occur during the development of the running movement pattern in children. Various biomechanical variables of the right running stride were analyzed, from sixty-three male subjects, with an age range of six to twelve years inclusive.

Prior to the taking of data from film, several preliminary measures were made. These included distance conversion factors, film frame rates, and time per frame. Calculations of these measures were made for each block of subjects, segmented by either a film change or the beginning of a new testing session.

Within the contents of this chapter, the results from the biomechanical investigation will be reported in three different areas. These areas will consist of: temporal data, kinematic data and angular data.

TEMPORAL DATA

For the purpose of temporal analysis of the right running stride, three measures were taken: time of stride, time of single support and time of flight.

As time of stride is the reciprocal of stride rate, one would expect the time of stride to decrease if there was an increase in the stride rate by the runners. Table I lists the times for the respective age groups to perform the right running stride. Table II lists the accompanying analysis of

TABLE I

MEAN TIME FOR THE COMPLETION OF THE RIGHT RUNNING STRIDE (SECONDS)

Age Group (years)	6	7	8	9	10	11	12
Mean	.27	.25	.26	.26	.27	.24	.24
Standard Deviation	.06	.03	.02	.05	.05	.04	.04

TABLE II

ANALYSIS OF VARIANCE FOR MEAN TIME FOR THE COMPLETION OF THE RIGHT RUNNING STRIDE

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	8.52	6	1.42	
Within Groups	109.20	56	1.95	.73*
Total	117.72	62		

* No significant differences at less than the .05 level.

variance table, for time of stride. The results for time of stride (F = .73) shows no significant difference in the mean values for the age groups analyzed at less than the .05 level (Table II).

Research into the area of time of stride (Sinning and Forsyth 1970, Hoshikawa, Matsui and Miyashita 1973) has generally shown that as the runner becomes more proficient, and attains a higher horizontal velocity, the time of stride decreases accordingly. From this study, the result for time of stride indicates that as the child grows older, and achieves a greater horizontal velocity, there is no appreciable change in the time of stride.

Studies in which the periods of single support and non-support were investigated have generally indicated that as the horizontal velocity increases the period of single support becomes shorter while the period of non-support becomes longer (Luhtanen and Komi 1978, Nelson and Osterhoudt 1971).

Table III lists the times of single support. The accompanying analysis of variance table is listed in table IV. The mean times of single support ranged from .20 seconds for the ten year old age group to .17 seconds for both the eleven and twelve year old age groups. The F-ratio from the analysis of variance table for single support (Table IV) was not significant at less than the .05 level (F = 1.01) and this indicates that across the seven different age groups analyzed, as horizontal velocity increased, there was no significant decrease in the time of single support.

TABLE III

MEAN TIME FOR SINGLE SUPPORT OF THE RIGHT RUNNING STRIDE (SECOND)

Age Group (years)	6	7	8	9	10	11	12
Mean	.19	.18	.19	.19	.20	.17	.17
Standard Deviation	.04	.03	.02	.03	.04	.03	.03

TABLE IV

ANALYSIS OF VARIANCE FOR MEAN TIME OF SINGLE SUPPORT

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	6.52	6	1.09	
Within Groups	60.48	56	1.08	1.01*
Total	67.00	62		

* No significant differences at less than the .05 level.

The corresponding mean percentage of time of single support (Table V) compared to the total time of stride ranged from, 69.91 percent for the six year old age group to 73.64 percent for the eight year old age group. The percentages were so close, that no trends were apparent and analysis of variance (Table VI) produced an F-ratio of only .62 which did not meet the requirements for statistical significance at the .05 level.

Time of flight involves the concept, that the older the runner, the greater the power the runner will generate at the point of take off, resulting in a longer flight time. Table VII lists the times of flight for the seven age groups analyzed. The accompanying analysis of variance table is listed in table VIII. The range of mean times of flight was .08 seconds for the six year old age group, with the remaining six age groups, seven to twelve inclusive, all having a mean value of .07 seconds. The F-ratio from the analysis of variance table for time of flight (Table VIII) was not significant at less than the .05 level (F = .45) and this indicates no statistically significant trends developing across the seven age groups analyzed.

The corresponding mean percentage of time of flight (Table IX) compared to the total time of stride ranged from, 26.36 percent for the eight year old age group to 30.09 percent for the six year old age group. The F-ratio (Table X) for percent of flight was .62, which did not meet the requirements for statistical significance at less than the .05

TABLE V

MEAN PERCENTAGE FOR SINGLE SUPPORT OF THE RIGHT RUNNING STRIDE

Age Group (years)	6	7	8	9	10	11	12
Mean	69.91	72.10	73.64	73.48	73.48	70.81	71.75
Standard Deviation	5.30	6.21	3.86	4.37	5.28	5.12	6.41

TABLE VI

ANALYSIS OF VARIANCE FOR MEAN PERCENTAGE OF SINGLE SUPPORT

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	105.71	6	17.62	
Within Groups	1582.26	56	28.25	.62*
Total	1687.97	62		

* No significant differences at less than the .05 level.

TABLE VII

MEAN TIME FOR FLIGHT OF THE RIGHT RUNNING STRIDE (SECONDS)

Age Group (years)	6	7	8	9	10	11	12
Mean	.08	.07	.07	.07	.07	.07	.07
Standard Deviation	.02	.02	.01	.02	.02	.02	.03

TABLE VIII

ANALYSIS OF VARIANCE FOR MEAN TIME OF FLIGHT

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	10.92	6	1.82	
Within Groups	227.92	56	4.07	.45*
Total	238.84	62		

* No significant differences at less than the .05 level.

TABLE IX

MEAN PERCENTAGE FOR FLIGHT OF THE RIGHT RUNNING STRIDE

Age Group (years)	6	7	8	9	10	11	12
Mean	30.09	27.90	26.36	26.52	26.52	29.19	28.25
Standard Deviation	5.30	6.21	3.86	4.37	5.28	5.12	6.41

TABLE X

ANALYSIS OF VARIANCE FOR MEAN PERCENTAGE OF FLIGHT

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	105.68	6	17.61	
Within Groups	1582.42	56	28.26	.62*
Total	1688.10	62		

* No significant differences at less than the .05 level.

level.

The results for both time of single support and time of flight are not in accordance with other findings from similar research (Clouse 1959, Dittmer 1962, Fortney 1963). The results of this study indicate that there were no statistically significant differences in magnitude of either time of single support or time of flight, as horizontal velocity increased across the age groups analyzed.

KINEMATIC DATA

The reporting of the kinematic data will consist of the following variables: horizontal velocity, stride length, stride rate, and relative foot velocity.

Researchers (Clouse 1959, Dittmer 1962, Fortney 1963, Beck 1966) who have analyzed childrens developmental running patterns, are in agreement with the concept of horizontal velocity increasing across age groups, although the results from Hebbelinck, Borms and Duquet (1974) study indicate a decline in the horizontal velocity of runners until age twelve, when there is a sharp increase in horizontal velocity.

Table XI lists the horizontal velocities for the seven age groups analyzed. The accompanying analysis of variance table is listed in table XII. The range of mean velocities for the seven age groups was 4.35 meters per second for the six year old age group to 6.48 meters per second for the twelve year old age group. The F-ratio of 7.76 (Table XII) was found to be statistically significant at the desired level of confidence ($p < .05$). This indicates that a statistically

TABLE XI

MEAN HORIZONTAL VELOCITY OF THE RIGHT RUNNING STRIDE (METERS/SEC.)

Age Group (years)	6	7	8	9	10	11	12
Mean	4.35	5.07	5.15	5.29	5.06	6.12	6.48
Standard Deviation	.85	.68	.69	.77	.63	.87	.81

TABLE XII

ANALYSIS OF VARIANCE FOR MEAN HORIZONTAL VELOCITY FOR THE RIGHT RUNNING STRIDE

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	27.10	6	4.52	
Within Groups	32.60	56	.58	7.76**
Total	59.70	62		

** Significant at less than the .05 level.

significant difference exists between the various age groups analyzed. A Scheffé method of post hoc analysis was used at the .05 level of significance to reveal that statistically significant differences in horizontal velocity existed between the following different age groups; six and eleven, six and twelve, seven and twelve, eight and twelve, and ten and twelve. This result supports the hypothesis, that horizontal velocity increases as the age of the runner increases.

Studies (Luhtanen and Komi 1978, Nelson and Osterhoudt 1971, Sinning and Forsyth 1970) have found that stride length plays a greater role than stride rate in changing running velocities at lower speeds, but at near maximal velocity, changes in stride rate are a greater contributor to the attainment of high speeds. This study was concerned only with maximal horizontal velocity, and how both stride length and stride rate changed in magnitude across the different age groups.

Table XIII lists the stride lengths for the seven age groups analyzed. The accompanying analysis of variance table is listed in table XIV. The range of mean stride lengths was 1.14 meters for the six year old age group to 1.54 meters for the twelve year old age group. The F-ratio of 6.60 (Table XIV), was found to be statistically significant at less than the .05 level, and this indicates that a significant difference in stride lengths exists for the age groups analyzed. The subsequent Scheffé method of post hoc analysis, with a .05

TABLE XIII

MEAN LENGTH OF THE RIGHT RUNNING STRIDE (METERS)

Age Group (years)	6	7	8	9	10	11	12
Mean	1.14	1.26	1.33	1.33	1.33	1.43	1.54
Standard Deviation	.09	.12	.13	.11	.16	.12	.23

TABLE XIV

ANALYSIS OF VARIANCE FOR MEAN LENGTH OF RIGHT RUNNING STRIDE

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	.84	6	.14	
Within Groups	1.18	56	.02	6.60**
Total	2.02	62		

** Significant at less than the .05 level.

of significance, revealed that the statistically significant differences in stride length existed between the following age groups; six and eleven, six and twelve. This result reflects the concept that the older the runner, the greater the power he will generate during take off, resulting in a greater stride length. The resultant velocity vector at the point of take off, must also be optimal to assist in the achievement of a long stride length.

A reciprocal relationship exists between time of stride and stride rate. Therefore, it might be expected that if a runner had a decrease in time of stride, there would be an accompanying increase in the runner's stride rate. The results from this study showed no apparent change in the magnitude of time of stride across the seven age groups analyzed.

Table XV lists the mean stride rates for the seven different age groups analyzed. The accompanying analysis of variance table is listed in table XVI. The mean range for stride rate was from 3.82 strides per second for the six year old age group to 4.30 strides per second for the eleven year old age group. The F-ratio (F = .78) did not meet the requirements for statistical significance at less than the .05 level. This result seems to conflict with the general understanding, that at near maximal horizontal velocity, the stride rate is a more significant contributor than stride length to the attainment of velocity.

At maximal velocity, a runner must recover the foot as

TABLE XV

MEAN STRIDE RATE FOR THE RIGHT RUNNING STRIDE (STRIDES/SEC.)

Age Group (years)	6	7	8	9	10	11	12
Mean	3.82	4.04	3.87	4.01	3.87	4.30	4.27
Standard Deviation	.76	.49	.25	.78	.69	.71	.71

TABLE XVI

ANALYSIS OF VARIANCE FOR MEAN STRIDE RATE OF THE RIGHT RUNNING STRIDE

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	2.01	6	.34	
Within Groups	24.18	56	.43	.78*
Total	26.19	62		

* No significant differences at less than the .05 level.

quickly as possible and then, during the latter stages of recovery decrease the forward velocity of the foot and effectively position it on the ground to minimize any possible retarding ground reaction. Table XVII lists the relative foot velocities for the seven age groups analyzed. The range of mean foot velocities was -.21 meters per second for the eight year old age group to -2.47 meters per second for the ten year old age group. Table XVIII lists the analysis of variance table for relative foot velocities. The F-ratio (F = 2.29) showed a statistically significant difference in the mean values for the age groups analyzed at less than the .05 level. This indicates that a statistically significant difference exists between the various age groups analyzed. A Scheffé method of post hoc analysis was used at the .05 level of significance to reveal that statistically significant differences in relative foot velocities existed between the combined results of eight and twelve year olds and all other possible paired combinations.

Both Fenn (1930) and later Dillman (1971) found that about halfway through the final period of flight, the lower leg begins to rotate backward about the knee, thus having a great effect in reducing the forward horizontal velocity of the foot. Ideally as the runner increases in age and becomes more proficient at the skill, the relative foot velocity should decrease in magnitude and theoretically, as well as practically, produce negative values. The results from this study indicate that relative foot velocity is not used effectively by

TABLE XVII

MEAN RELATIVE FOOT VELOCITY OF THE RIGHT RUNNING STRIDE (METERS/SEC.)

Age Group (years)	6	7	8	9	10	11	12
Mean	-2.21	-1.46	-.21	-1.43	-2.47	-1.18	-.92
Standard Deviation	1.62	1.66	1.70	1.32	1.27	.76	1.71

TABLE XVIII

ANALYSIS OF VARIANCE FOR MEAN RELATIVE FOOT VELOCITY FOR THE RIGHT RUNNING STRIDE

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	29.00	6	4.83	
Within Groups	117.93	56	2.11	2.29**
Total	146.93	62		

** Significant at less than the .05 level.

the different age groups analyzed, in overcoming retarding ground reaction forces at the point of contact.

ANGULAR DATA

The results from this section will be reported in two areas; first the ankle and knee angles at take off, second, the hip angles at the four different phases of the running stride.

Sinning and Forsyth's (1970) results of study of the ankle indicate no appreciable change in either maximum dorsiflexion or plantar flexion of the ankle joint as running velocity increased. The results from this study are in accordance with previous reports, in that the range of ankle joint movement remains relatively constant for the different age groups. Table XIX lists the ankle angles at the point of take off, in radians, for the seven age groups analyzed. The range for the mean ankle angles at the point of take off was 2.55 radians (145.7°) for the nine year old age group to 2.61 radians (149.1°) for the eight year old age group. The range of angles was so small that no trends were apparent and analysis of variance (Table XX) produced an F-ratio of only .43 which did not meet the requirements for statistical significance at the .05 level.

Hoshikawa, Matsui and Miyashita (1973) found that the angle range of the knee joint at take off became considerably wider with an increase in velocity, but the ankle joint remained relatively the same angle at take off.

Table XXI lists the knee angles at the point of take off,

TABLE XIX

MEAN ANKLE ANGLE AT POINT OF TAKE OFF (RADIANS)

Age Group (years)	6	7	8	9	10	11	12
Mean	2.56	2.57	2.61	2.55	2.58	2.59	2.60
Standard Deviation	.09	.09	.08	.10	.14	.08	.10

TABLE XX

ANALYSIS OF VARIANCE FOR MEAN ANKLE ANGLE AT THE POINT OF TAKE OFF

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	2.57	6	.43	
Within Groups	57.00	56	1.02	.43*
Total	59.57	62		

* No significant differences at less than the .05 level.

TABLE XXI

MEAN KNEE ANGLE AT THE POINT OF TAKE OFF (RADIANS)

Age Group (years)	6	7	8	9	10	11	12
Mean	2.98	2.95	2.94	2.92	2.94	2.95	2.95
Standard Deviation	.10	.12	.11	.10	.08	.11	.09

TABLE XXII

ANALYSIS OF VARIANCE FOR MEAN KNEE ANGLE AT THE POINT OF TAKE OFF

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	1.69	6	.28	
Within Groups	57.00	56	1.02	.28*
Total	58.69	62		

* No significant differences at less than the .05 level.

in radians, for the seven age groups analyzed. The range of knee angles at the point of take off was so small that no trends were apparent and analysis of variance (Table XXII) produced and F-ratio of only .28 which did not meet the requirements for statistical significance at the .05 level.

In summary, the results showed that both the ankle and knee joints, at the point of take off remained relatively constant across the different age groups. These results are not in accordance with similar research on this topic.

HIP ANGLES

A hypothesis for the directional change in magnitude of the hip angles at various stages of the running stride was not made, due to either conflicting results or insufficient research on this topic. The necessity for complete hip joint extension is important though, as Hay (1973) feels it is probably one of the most common faults to be found in the techniques of sprinters.

Table XXIII lists the hip angles at the point of take off, in radians for the different age groups. The range for the mean hip angles at the point of take off was 2.84 radians (162.3°) for the ten year old age group to 2.93 radians (167.4°) for the eight year old age group. The F-ratio from the analysis of variance table (Table XXIV) for the hip angle at take off was not significant at less than the .05 level (F= 1.26) and this indicates no statistically significant trends developing across the seven age groups analyzed.

Table XXV lists the hip angles at mid-flight, in radians

TABLE XXIII

MEAN HIP ANGLE AT THE POINT
OF TAKE OFF (RADIANS)

Age Group (years)	6	7	8	9	10	11	12
Mean	2.90	2.89	2.93	2.92	2.84	2.87	2.90
Standard Deviation	.06	.12	.07	.07	.07	.07	.09

TABLE XXIV

ANALYSIS OF VARIANCE FOR MEAN HIP
ANGLE AT THE POINT OF TAKE OFF

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	50.40	6	8.40	
Within Groups	371.84	56	6.64	1.26*
Total	422.24	62		

* No significant differences at less than the .05 level.

TABLE XXV

MEAN HIP ANGLE AT THE POINT
OF MID-FLIGHT (RADIANS)

Age Group (years)	6	7	8	9	10	11	12
Mean	2.83	2.83	2.85	2.90	2.77	2.83	2.84
Standard Deviation	.07	.14	.12	.09	.07	.13	.14

TABLE XXVI

ANALYSIS OF VARIANCE FOR MEAN HIP
ANGLE AT THE POINT OF MID-FLIGHT

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	.07	6	.01	
Within Groups	.74	56	.01	.92*
Total	.81	62		

* No significant differences at less than the .05 level.

for the different age groups. The range for the mean hip angles at mid-flight was 2.77 radians (158.3°) for the ten year old age group to 2.90 radians (165.7°) for the nine year old age group. The F-ratio from the analysis of variance table (Table XXVI) for hip angle at mid-flight was not significant at less than the .05 level (F= .92) and this indicates no statistically significant trends developing across the age groups studied.

Table XXVII lists the hip angles at the point of touch down, in radians for the seven different age groups analyzed. The range for the mean hip angles at the point of touch down was 1.57 radians (89.7°) for the eight year old age group to 1.74 radians (99.4°) for the eleven year old age group. The F-ratio from the analysis of variance table (Table XXVIII) for hip angle at the point of touch down produced an F-ratio of 1.23 which did not meet the requirements for statistical significance at the .05 level.

The hip angle at mid-support gives an indication of the erectness or extension of the hip joint as the body passes over the base of support. Table XXIX lists the hip angles at mid-support, in radians for the seven age groups. The range for the mean hip angles at mid-support was 1.81 radians (103.4°) for the seven year old age group to 1.99 radians (113.7°) for the nine year old age group. The F-ratio from the analysis of variance table (Table XXX) for hip angle at mid-support was not significant at less than the .05 level (F= .64) and this indicates no statistically significant trends developing across

TABLE XXVII

MEAN HIP ANGLE AT THE POINT OF TOUCH DOWN (RADIANS)

Age Group (years)	6	7	8	9	10	11	12
Mean	1.70	1.58	1.57	1.73	1.68	1.74	1.64
Standard Deviation	.08	.31	.33	.08	.13	.09	.10

TABLE XXVIII

ANALYSIS OF VARIANCE FOR MEAN HIP ANGLE AT THE POINT OF TOUCH DOWN

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	.25	6	.04	
Within Groups	1.89	56	.03	1.23*
Total	2.14	62		

* No significant differences at less than the .05 level.

TABLE XXIX

MEAN HIP ANGLE AT THE POINT
OF MID-SUPPORT (RADIANS)

Age Group (years)	6	7	8	9	10	11	12
Mean	1.88	1.81	1.90	1.99	1.86	1.83	1.94
Standard Deviation	.12	.40	.14	.14	.10	.37	.25

TABLE XXX

ANALYSIS OF VARIANCE FOR MEAN HIP
ANGLE AT THE POINT OF MID-SUPPORT

Source	Sum of Squares	DF	Mean Square	F-Ratio
Between Groups	.25	6	.04	
Within Groups	3.58	56	.06	.64*
Total	3.83	62		

* No significant differences at less than the .05 level.

the seven age groups analyzed.

The results for the hip angle at the four different phases of the running stride, do not signify that the hip angle is not an important variable in the completion of the running stride. Rather, they suggest that the subjects perform with similar hip extension patterns over all age groups.

CORRELATION ANALYSIS FOR MATURATION

The body height of individuals, as mentioned earlier, is an accurate measure in the determination of chronological age levels. Therefore a correlation between body height and certain technique variables was undertaken, in an attempt to determine if maturation is a factor in running technique. The variables that were correlated with height were the following: horizontal velocity, stride length, time of flight and relative foot velocity.

The results from Table XXXI, indicate that there is a high correlation (statistically significant at the $p < .05$ level) between the subjects' body height and horizontal velocity and time of flight for this study. These results indicate that as height increases, there are significant accompanying changes in running velocity and flight time. This reflects the fact that as the child increases in height, there is an accompanying increase in strength, which is a reflection of the power that the child can generate during the running movement pattern.

The running pattern of children has been developed by the age of six. Certain additional developmental trends, however, are apparent from ages six to twelve, as the results from this

TABLE XXXI

CORRELATION ANALYSIS (r) FOR MATURATION

Subject's Body Height	vs	Mechanical Variables	r
Height		Horizontal Velocity	.74**
Height		Stride Length	.01
Height		Time of Flight	.45**
Height		Relative Foot Velocity	.28

** Significant at less than the .05 level.

study indicate.

The results from the temporal data produced no statistically significant differences across the age groups analyzed. Previous research has confirmed that as horizontal velocity is increased, there is a decrease in time of stride. Also accompanying this change in horizontal velocity, time of single support is decreased and time of flight is increased in magnitude. The results obtained from this study, which showed an increase in horizontal velocity across the age groups, produced no change in magnitude in time of stride, time of single support, or time of flight ($p > .05$).

The various body segment angles that were measured throughout the running stride, produced no statistically significant differences across the seven different age groups ($p > .05$). The results from this section indicate that as horizontal velocity increases across the age range, subjects perform with similar ankle, knee and hip extension patterns.

Power is an essential component in the efficient completion of the running stride. The magnitude of the power the runner uses during the running stride is reflected by the magnitude of both the horizontal velocity and stride length ($p < .05$). For a runner to become more powerful, he needs to increase the amount of work he is performing or decrease the time in which it takes him to perform the work, or a combination of both these changes. From the temporal data, it was found that the various timing components of the stride did not vary significantly across the age groups analyzed. Therefore it seems the work being performed by the different age groups increased, resulting in a greater magnitude of power and as a result, greater stride lengths. Thus, as the child matures physically, he needs greater power to propel him through the various stages of the running stride. A statistically significant difference ($p < .05$) was found to exist in stride length for the age groups analyzed. This indicates that as the child grows older, with an accompanying increase in power, he can utilize this power during the propulsive phase of support to produce a greater stride length.

Horizontal velocity is the product of stride length multiplied by stride rate. A statistically significant difference ($p < .05$) was found to exist for stride length. Stride rate produced no statistically significant differences ($p > .05$) between the age groups analyzed. Thus the ability of the runner to increase his power during the propulsive phase of support, not only produced a greater stride length, but also created a greater horizontal velocity.

In summary, apart from horizontal velocity and stride length which are related to the concept of power and how effectively the runner can produce an increase in power, the running patterns do not change significantly from ages six to twelve inclusive.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to assess the magnitude of technique changes which occur during the development of the running movement pattern in children. Sixty-three male subjects were filmed by a Locam 16mm, motor driven camera, set to operate at a hundred frames per second. Each subject was instructed to run approximately twenty meters before entering the filming area. Once the runners entered the filming area (approximately five meters in length) they were to maintain their maximum running velocity. A side view of each performer's right stride was recorded.

Various temporal components associated with the technique changes in the developmental patterns of childrens running performance were investigated. Time of stride studies have reported a decrease in magnitude when horizontal velocity is increased, as well as when the runner increases in age from infancy to adolescence. The results for this study for time of stride, produced no statistically significant differences across the age groups analyzed. This result is not in accord with previous research which has studied both elite and child runners at maximal running velocity and their change in magnitude of time of stride. The time taken to perform the running stride does not alter significantly from ages six to twelve. The inability of the child as he grows older to decrease his time of stride, even though he increases his horizontal velocity, suggests the need for further examination of the stride time component relationships.

Studies of both elite and child runners which have analyzed the times of single support and flight, and their percentages relative to the total stride, have found similar results. That is, as horizontal velocity increased, the time of flight was found to increase slightly, while the time of single support decreased significantly. Also the percentages of single support and flight showed similar changes in magnitude. The results from this study on times of single support and flight, with their accompanying percentages, did not produce similar results as reported in other studies on the same topic and therefore it appears that further research should be directed toward resolving this problem of conflicting evidence.

Time of flight is determined by those factors that govern the flight of all projectiles: the speed, angle and height of the center of gravity at the point of take off. The results show that the differences in speed between the age groups analyzed were statistically significant. A more complete understanding of the reasons for no change in the time of flight therefore, awaits further examination of the other two factors: angle and center of gravity position at take off.

Time of single support, from previous research dealing with both elite and child runners, should decrease when horizontal velocity increases. For this study, even though horizontal velocity increased, there was no appreciable change in the time of single support. Force is the instigator of movement. It is necessary to have a large horizontal component of force during the thrust phase in order to propel the body forward. This is manifest in the power that the runner can generate while he is in the single support phase of the stride. The results show that the time the runner spends in the single support phase does not change significantly. Thus to increase the component of power, and subsequently produce a higher horizontal velocity, the runner must have increased the amount of work that he was doing while in the single support phase of the stride. The ability of the runner to create as much power as possible, during the time he is in contact with the ground, seems to be a limiting factor in the efficient completion of the running stride. Future research should concentrate on the concept of the power that the runner can generate, as one distinguishing factor that causes children to attain a higher maximal running velocity.

The kinematic data measured in this study produced three statistically significant differences in the magnitude of the technique changes analyzed. A reciprocal relationship exists between the time of stride and stride rate. Research for both elite and child runners, has shown that when a runner has a decrease in time of stride, there is an accompanying increase in the runner's stride rate. The results for time of stride produced no statistically significant differences across the age groups analyzed. Thus the stride rate also produced no statistically significant difference in magnitude across the age range. This result is not in accord with results from previous developmental studies and suggests that runners in the age range studied can more easily increase velocity by increasing applied force rather than the rate of segmental movements. This area warrants further investigation to discover when stride rate does become a significant factor during the development of the running pattern.

The interrelationship between stride rate and stride length, and how they contribute to maximal running velocities for elite runners, has been well documented. No statistically significant difference was found to exist for stride rate, but one was found for stride length ($p<.05$). The ability of the runner to maximize the three factors which determine the flight of a projectile (speed, angle and height of the center of gravity at take off) could be significant factors in the achievement of a long running stride. Other possible causes for this significant difference in stride length might be the length of the lower limbs. A lever can serve to increase the distance through which a body can be moved in a given time, or to increase the speed with which a body can be moved. Thus a lever can be used to effectively increase the speed at which a muscular force moves a body.

Horizontal velocity is the product of stride length times stride rate. A statistically significant difference was found to exist between the age groups analyzed for horizontal velocity ($p<.05$). The ability of the child to increase his running power as he matures physically is reflected in this increase in running velocity. Though from ages seven to ten inclusive, the magnitude of horizontal velocity remained relatively constant, indicating that for these age groups, as far as running velocity is concerned, they are ideally matched for competition.

It seems that increases in running velocity are accompained by significant increases in stride length, while stride rate is of little importance in contributing to the maximal running velocities of the age groups analyzed.

Relative foot velocity, or the ability to have the touch down foot moving in the opposite direction to the total body's motion at the point of contact, to eliminate retarding ground reaction forces, produced a statistically significant difference between the age groups analyzed ($p<.05$). Even though a significant difference was found to exist, the nature of the change in magnitude for relative foot velocity was not one of a continuous pattern. Thus the ability of runners to more effectively use this technique in the completion of the running stride, does not appear to undergo a systematic change over the age range studied.

In summary, for the kinematic data the increases in running velocity that were found to occur, were accompained by significant increases in stride length, but relatively little change in stride rate. Possible factors which could contribute to the increase in stride length and warrant further investigation are the length of the lower limbs and their use as levers, and the ability of the runner to generate maximal power propulsion. Stride rate requires further analysis to discover when it does become a significant contributor in running velocity changes. Although relative foot velocity varied significantly, the trend across the age groups was not one of a continuous nature. Thus indicating the inability of the runners to perform this technique with any consistency. Future investigation is warranted to discover when and why this technique variable starts to develop in the childrens running pattern.

Full extension of the leg at take off to maximize the forces propelling the body forward is essential. Also the longer the lever, the more effective it is at increasing the speed at which a muscular force can propel the body forward assuming that applied muscle forces are large enough to overcome larger moments of inertia. Previous research on elite runners has shown that as running velocity is increased, there are no appreciable changes in the ankle angle at take off. This study found similar results for the age groups analyzed, when running velocity increased from ages six to twelve. As running velocity increases, studies have shown that there is an accompanying increase in the knee angle at take off. This assists in the attainment of maximal running velocity of elite runners. The range of knee angles at the point of take off, as running velocity increased across the age range for this study, was so small that no trends were apparent for this variable. Upon examination of the knee angle at take off, the magnitude of extension was so large, that no further increase in extension could be achieved. Thus indicating that full extension of the knee at take off is already a part of the running pattern by the age of six and does not change in magnitude through age twelve.

Due to conflicting results and insufficient research on the area of hip extension during various stages of the running stride for both elite and child runners, a prediction as to the directionality of change was not made. Full hip extension, however, at the completion of the stride, is important. By making the appropriate adjustments in the extension of his trunk, the sprinter is able to control the rotation of his body about its transverse axis, caused by the forces that are encountered when in contact with the ground. The results for the four various stages of the stride produced no significant differences across the age groups analyzed. The three phases of the stride in which runners were in contact with the ground (take off, touch down, mid-support) all have vertical and horizontal reaction forces being applied through the point of contact. These forces tend to cause rotation of the body, which can inhibit the performance of the runner. This indicates the need for future research into this area to distinguish the range of hip extension that produces the most efficient use of the powerful hip extensor muscles during running.

In summary, the angular data revealed that at take off, the angle of the ankle remained relatively constant when running velocity increased, as previous research on elite runners has confirmed. The angle of the knee at take off, showed no significant change in magnitude when running velocity increased, even though other studies on elite runners have found this. The hip extension pattern for the four various phases of the running movement pattern produced similar results indicating the need for future research to analysis the importance of this aspect of technique during the running stride.

IMPLICATIONS OF THE STUDY

Running is one of the most basic forms of locomotion. In fact most children have a natural inclination to run rather than walk. As they pass through the various stages of youth and adolescence, and engage in sport and physical recreation, it is found that running becomes a large part of their world. It does not have to form the specific goal of an activity, but it can provide a means to an end in countless activities. The results from this study indicate, that by the age of six the mature running movement pattern of boys is well established. In fact so much so, that few statistically significant differences were found to exist among the variables analyzed between the ages of six and twelve inclusive.

Up until the age of ten, the running velocities did not alter significantly, thus methods of categorization to match running velocities other than the traditional ones of age or grade level should be employed. An example of this may be found in the significant correlation that was found to exist between body height and horizontal velocity (r=.74). The use of a child's body height or some other maturational variable in the determination of the performance category he should compete in needs to be explored further. Also the body weight of the child in view of its correlation with running velocity could add valuable insight into this concept of categorization of children.

Strength is the ability of the organism to mobilize force in an effort to overcome resistance. Muscles tend to increase in size as they are used. Also, strength is developmental, and increases with age from birth to maturity. The lack of strength may be a limiting factor in effective running velocities of children. This is exemplified by the concept of power, and how effectively children at various ages use it. Power is work divided by the time taken to do that work and it appears to be a critical factor in the development of running speed. The temporal or timing variables analyzed in this study did not change across the age range, especially in time of single support, where the forces to propel the body forward are initiated. Thus a significant contributor to higher running velocities, must be the component of work, and how effectively it was employed to achieve the higher running velocities.

Work is the product of force, multiplied by the distance over which that force was applied. Even though no investigation was carried out, it would seem that the distance over which the force was being applied in the support phase of the stride, did not vary considerably. Therefore it is most likely that the force being applied contributes significantly to the increase in magnitude of work being performed during the support phase of the stride.

Future research into the causes of higher running velocities of children should center on the following factors in an attempt to explain the differences in magnitude: the force being exerted by the runner in the support phase of the stride, the acceleration patterns throughout the support phase, the distance over which the force is being applied, and the age levels at which the time component of the work being performed start to decrease significantly. Also, studies should concentrate on the comparison of male and female child runners to distinguish if one sex has a distinct advantage in their running patterns at certain age levels. Further research should be undertaken to determine if maturational factors, such as body height and weight, could be viable alternatives to the more traditional methods of categorizing children for competition.

In summary, apart from horizontal velocity and stride length which are related to the concept of power and how effectively the runner can produce an increase in power, the running patterns do not change significantly from ages six to twelve.

Based on the results obtained in this study, the following conclusions are warranted.

1) There is a significant increase in the maximum running velocity of males as age increase from six to twelve inclusive.

2) Time of single support does not change significantly between ages six to twelve. The power that the child can generate does change, therefore the work being performed must be the significant contributor to the attainment of maximum power.

3) Increases in running velocity of males between six and twelve years old are accompained by significant increases in stride length but relatively little change in stride rate.

4) Relative velocity of the recovery foot at touch down is the only technique factor in the running movement patterns of male children which changes significantly between the ages of six to twelve inclusive.

5) The ankle, knee and hip extension patterns during maximum running velocities for male children between the ages of six to

twelve, do not alter significantly.

6) There is no difference in maximum running velocity between the ages seven to ten inclusive. Therefore the use of age as a category level for competition does not seem to be warranted for this age range.

7) There is a significant correlation between body height and childrens maximum running velocities. The use of body height as an alternate method of categorizing childrens competition levels should be investigated further.

8) It appears that by the age of six, the fundamental male running pattern has been developed, and that the only significant changes that occur up to age twelve are in strength and power. These changes are reflected in the older subjects' ability to cover more distance during each stride which in turn produces significantly higher horizontal velocities.

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APPENDIX A

STRUCTURAL VARIABLES OF THE SUBJECTS

In the raw data tables (Table XXXII and Table XXXIII), the structural and mechanical variables are abbreviated as follows:

1. YR Age (years)
2. HT Height (m)
3. WT Weight (Kg)
4. HV Horizontal Velocity (m/sec)
5. SR Stride Rate (sec)
6. SL Stride Length (m)
7. TS Time of Stride (sec)
8. FT Flight Time (sec)
9. SST Single Support Time (sec)
10. PF Percent of Flight (%)
11. PSS Percent of Single Support (%)
12. HTO Hip Angle at Take Off (Radians)
13. HMF Hip Angle at Mid-Flight (Radians)
14. HTD Hip Angle at Touch Down (Radians)
15. HMS Hip Angle at Mid-Support (Radians)
16. ATO Ankle Angle at Take Off (Radians)
17. KTO Knee Angle at Take Off (Radians)
18. RFV Relative Foot Velocity (m/sec)

TABLE XXXII

STRUCTURAL VARIABLES

Subject	Age(yr)	HT(m)	WT(Kg)
1	8	1.34	26.8
2	6	1.17	20.0
3	7	1.18	22.7
4	6	1.19	25.0
5	7	1.20	23.2
6	6	1.19	21.8
7	7	1.34	39.5
8	6	1.15	19.5
9	6	1.23	24.1
10	7	1.18	20.0
11	7	1.27	25.0
12	7	1.27	23.6
13	7	1.19	21.8
14	8	1.21	20.0
15	8	1.32	28.6
16	8	1.22	23.6
17	9	1.41	30.9
18	9	1.36	28.6
19	9	1.39	29.5
20	9	1.33	30.0
21	9	1.44	38.2
22	9	1.40	30.5
23	11	1.52	35.0
24	11	1.52	36.8
25	11	1.41	33.2
26	11	1.47	39.5
27	11	1.50	44.1
28	11	1.41	30.9
29	11	1.29	27.3
30	11	1.49	45.0
31	11	1.64	81.8
32	12	1.41	38.6
33	12	1.44	34.1
34	12	1.41	34.1
35	12	1.64	56.8
36	12	1.55	43.2
37	12	1.51	41.4
38	6	1.15	19.1
39	6	1.18	20.9
40	7	1.32	25.9
41	7	1.38	30.5
42	8	1.37	29.1
43	8	1.28	29.5
44	8	1.33	28.6
45	8	1.34	29.5
46	9	1.53	35.5

Subject	Age (yr)	HT (m)	WT (Kg)
47	9	1.34	28.6
48	9	1.46	35.5
49	9	1.40	37.3
50	10	1.44	35.0
51	10	1.36	30.0
52	10	1.46	38.2
53	10	1.48	44.5
54	10	1.50	45.9
55	10	1.54	59.1
56	10	1.48	50.5
57	10	1.46	52.7
58	11	1.43	38.2
59	12	1.46	36.4
60	12	1.61	40.5
61	10	1.37	35.5
62	12	1.61	45.9
63	12	1.75	71.8

APPENDIX B

MECHANICAL VARIABLES OF THE RIGHT STRIDE

TABLE XXXIII

MECHANICAL VARIABLES OF THE RIGHT STRIDE

Subject	1	2	3	4	5	6	7	8
HV	4.28	5.13	3.99	3.26	4.74	3.17	5.05	5.13
SR	3.70	4.33	3.91	2.80	3.91	2.70	4.46	4.59
SL	1.16	1.18	1.02	1.16	1.21	1.17	1.13	1.12
TS	.27	.23	.26	.36	.26	.37	.22	.22
FT	.05	.07	.06	.12	.05	.10	.05	.06
SST	.22	.16	.20	.24	.21	.27	.17	.16
PF	20.00	28.57	20.00	33.33	20.00	28.00	22.73	27.78
PSS	80.00	71.43	80.00	66.67	80.00	72.00	77.27	72.22
HTO	2.85	2.89	2.88	2.88	3.13	2.87	2.70	3.01
HMF	2.74	2.84	2.76	2.89	3.09	2.71	2.62	2.86
HTD	.79	1.86	1.72	1.62	1.59	1.69	1.72	1.69
HMS	1.84	1.99	1.98	1.97	2.03	1.65	1.73	1.86
ATO	2.61	2.66	2.56	2.64	2.48	2.61	2.52	2.44
KTO	2.95	3.01	2.74	2.82	2.86	2.93	3.02	3.03
RFV	-2.37	-3.64	-3.75	-2.51	+1.25	-1.09	-2.35	-2.77

Subject	9	10	11	12	13	14	15	16
HV	4.84	5.15	6.29	5.42	5.04	4.94	5.81	6.27
SR	3.85	3.89	4.92	4.27	3.86	2.78	4.27	4.03
SL	1.26	1.32	1.28	1.27	1.31	1.31	1.36	1.56
TS	.26	.26	.20	.23	.26	.26	.23	.25
FT	.10	.09	.07	.07	.10	.08	.06	.08
SST	.16	.17	.13	.16	.16	.18	.17	.17
PF	39.13	33.33	33.33	30.00	37.50	30.43	25.00	30.43
PSS	60.87	66.67	66.67	70.00	62.50	69.57	75.00	69.57
HTO	2.94	2.86	2.86	2.90	2.96	2.85	2.94	2.97
HMF	2.93	2.87	2.87	2.77	2.91	2.74	2.88	2.84
HTD	1.70	.79	1.78	1.74	1.68	1.64	1.78	1.58
HMS	1.88	1.91	2.14	1.85	2.03	1.83	1.99	1.82
ATO	2.60	2.57	2.70	2.67	2.67	2.55	2.69	2.71
KTO	3.02	3.00	3.05	2.90	3.11	3.00	2.86	2.92
RFV	-4.39	-3.89	-1.28	-.50	-.30	+.14	-.28	+.05

Subject	17	18	19	20	21	22	23	24
HV	6.34	6.17	5.99	5.45	4.16	5.17	5.54	6.36
SR	5.16	5.07	4.31	3.57	2.96	3.78	3.95	4.63
SL	1.23	1.22	1.39	1.53	1.40	1.37	1.40	1.37
TS	.19	.20	.23	.28	.34	.26	.25	.22
FT	.04	.05	.07	.08	.09	.06	.06	.07
SST	.15	.15	.16	.20	.25	.20	.19	.15
PF	21.05	23.53	31.58	28.00	25.81	21.74	22.73	33.33
PSS	78.95	76.47	68.42	72.00	74.19	78.26	77.27	66.67
HTO	2.84	2.80	3.03	2.95	2.95	2.99	2.90	2.89
HMF	2.90	2.74	3.03	2.94	2.83	2.91	2.88	2.79
HTD	1.72	1.77	1.77	1.73	1.61	1.59	1.80	1.70
HMS	2.04	1.85	2.25	1.92	1.93	1.95	1.94	1.91
ATO	2.63	2.31	2.54	2.65	2.63	2.60	2.71	2.50
KTO	2.86	2.77	2.98	2.93	2.82	2.84	2.95	2.88
RFV	+.63	-2.21	-1.57	-.48	-2.34	-.14	-1.53	-.17

Subject	25	26	27	28	29	30	31	32
HV	6.72	4.54	5.96	7.92	5.72	6.30	6.23	5.94
SR	4.55	3.37	4.10	5.95	4.03	4.04	3.68	4.05
SL	1.48	1.35	1.45	1.33	1.42	1.56	1.69	1.47
TS	.22	.30	.24	.17	.25	.25	.27	.25
FT	.07	.07	.07	.05	.07	.07	.11	.05
SST	.15	.23	.17	.12	.18	.18	.16	.20
PF	30.00	21.43	30.43	28.57	26.09	28.57	39.13	20.83
PSS	70.00	78.57	69.57	71.43	73.91	71.43	60.87	79.17
HTO	2.92	2.79	3.02	2.88	2.84	2.80	2.86	3.03
HMF	2.85	2.69	3.12	2.83	2.80	2.71	2.93	3.03
HTD	1.68	1.69	1.77	1.55	1.86	1.73	1.79	1.63
HMS	1.94	1.74	1.99	2.03	1.97	1.95	2.01	2.43
ATO	2.65	2.60	2.56	2.64	2.59	2.58	2.62	2.71
KTO	2.86	2.77	3.07	2.88	2.99	2.92	3.14	2.97
RFV	-.97	-1.11	+.40	-1.34	-1.93	-1.63	-1.76	-.21

Subject	33	34	35	36	37	38	39	40
HV	6.40	6.24	6.33	7.35	5.51	4.08	4.85	4.34
SR	4.33	3.99	3.68	4.35	5.26	4.27	4.21	3.15
SL	1.48	1.56	1.72	1.69	1.05	.95	1.15	1.38
TS	.23	.25	.27	.23	.19	.23	.24	.32
FT	.09	.06	.07	.06	.04	.05	.08	.09
SST	.14	.19	.20	.17	.15	.18	.16	.23
PF	38.10	22.73	26.09	26.09	21.05	22.22	31.58	26.92
PSS	61.90	77.27	73.91	73.91	78.95	77.78	68.42	73.08
HTO	2.90	2.87	2.85	2.95	2.91	2.86	2.82	2.93
HMF	2.91	2.84	2.73	2.90	2.77	2.78	2.79	2.91
HTD	1.62	1.57	1.75	1.52	1.52	1.64	1.73	1.51
HMS	1.93	1.72	1.55	1.97	1.81	1.79	1.93	.79
ATO	2.49	2.57	2.40	2.69	2.71	2.47	2.50	2.48
KTO	3.13	2.96	3.00	3.01	2.85	2.93	3.12	3.03
RFV	+2.33	-.42	-1.63	-1.12	+.64	+.37	-1.41	-1.44

Subject	41	42	43	44	45	46	47	48
HV	5.57	4.55	5.14	4.61	5.62	5.29	4.19	4.68
SR	4.02	3.85	3.97	3.42	3.95	4.55	2.92	3.64
SL	1.39	1.18	1.30	1.35	1.42	1.16	1.43	1.29
TS	.25	.26	.25	.29	.25	.22	.34	.28
FT	.07	.06	.08	.07	.07	.06	.12	.07
SST	.18	.20	.17	.22	.18	.16	.22	.21
PF	27.27	22.73	30.00	25.00	27.27	27.78	34.38	22.73
PSS	72.73	77.27	70.00	75.00	72.73	72.22	65.62	72.27
HTO	2.78	2.98	2.83	3.02	2.98	2.90	2.92	2.91
HMF	2.67	2.96	2.67	3.04	2.91	2.95	2.86	3.01
HTD	1.66	1.74	1.80	1.59	1.63	1.70	1.88	1.73
HMS	1.83	2.08	1.65	1.97	2.02	1.99	1.83	2.22
ATO	2.50	2.67	2.62	2.49	2.53	2.48	2.53	2.53
KTO	2.82	2.73	3.03	3.06	2.96	2.99	3.10	2.95
RFV	-.85	+.81	-2.80	+.27	+2.50	-2.10	-3.89	-.51

Subject	49	50	51	52	53	54	55	56
HV	5.41	5.80	5.36	4.84	4.69	6.23	4.31	5.07
SR	4.11	4.52	4.13	3.94	3.64	5.06	3.13	3.99
SL	1.32	1.28	1.30	1.23	1.29	1.23	1.38	1.27
TS	.24	.22	.24	.25	.28	.20	.32	.25
FT	.07	.06	.07	.06	.07	.06	.07	.08
SST	.17	.16	.17	.19	.21	.14	.25	.17
PF	28.57	27.78	31.82	23.81	22.73	31.58	20.69	31.82
PSS	71.43	72.22	68.18	76.19	77.27	68.42	79.31	68.18
HTO	2.87	2.95	2.79	2.85	2.73	2.90	2.81	2.81
HMF	2.81	2.85	2.71	2.80	2.69	2.79	2.82	2.68
HTD	1.77	1.68	1.71	1.85	1.65	1.37	1.70	1.68
HMS	1.95	1.90	1.78	1.81	1.85	1.87	1.94	1.71
ATO	2.58	2.65	2.63	2.50	2.52	2.82	2.56	2.60
KTO	2.95	3.01	2.91	2.76	2.89	2.95	3.01	3.02
RFV	-1.65	-2.60	-4.49	-3.57	-3.07	-1.85	-.87	-2.52

Subject	57	58	59	60	61	62	63
HV	4.47	5.90	6.13	7.34	4.77	5.57	7.96
SR	3.64	4.66	4.04	5.26	2.78	2.95	4.78
SL	1.23	1.27	1.52	1.40	1.72	1.90	1.67
TS	.28	.21	.25	.19	.36	.34	.21
FT	.05	.07	.08	.06	.11	.13	.06
SST	.23	.14	.17	.13	.25	.21	.15
PF	18.18	31.58	33.33	30.00	30.30	37.93	26.32
PSS	81.82	68.42	66.67	70.00	69.70	62.07	73.68
HTO	2.81	2.78	2.86	2.76	2.88	3.06	2.84
HMF	2.86	2.68	2.73	2.61	2.75	3.03	2.80
HTD	1.80	1.79	1.81	1.76	1.67	1.59	1.66
HMS	2.06	.79	2.07	1.77	1.79	2.10	2.09
ATO	2.30	2.42	2.60	2.54	2.66	2.64	2.68
KTO	2.96	3.02	2.88	2.86	2.92	2.87	2.98
RFV	-.43	-2.83	-1.76	-3.54	-1.76	-1.51	-1.31

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