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A KINEMATIC ANALYSIS OF THE DEVELOPMENTAL
SEQUENCE OF KICKING USING A DIRECT
AND ANGLED APPROACH

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Alfred Henry Bransdorfer

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A KINEMATIC ANALYSIS OF THE DEVELOPMENTAL SEQUENCE OF KICKING USING A DIRECT AND ANGLED APPROACH

By

Alfred Henry Bransdorfer

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ABSTRACT

A KINEMATIC ANALYSIS OF THE DEVELOPMENTAL SEQUENCE
OF KICKING USING A DIRECT AND ANGLED APPROACH

By

Alfred Henry Bransdorfer

The purpose of this study was to examine and quantify the developmental sequence of kicking in children using direct and angled approaches to the ball. Twenty children, ranging from three to eight years of age participated in the study and was identified as one of the four classic stage levels of kicking development. Using the Aerial Performance Analysis System (A.P.A.S.) the subjects were video taped while kicking a standard youth size three soccer ball and the newly developed lightweight Micro-Soccer ball. Angular displacements, velocities, and accelerations of the kicking limb were calculated for data analysis.

Predicted trends were established for both approach types. Few of the predicted characteristics were found for the direct approach, whereas, most of the predicted characteristics were found for the angled approach. One major finding was knee flexion at contact for all four stages with both ball types during both approaches.

A segmental relationship of the kicking limb, where the thigh of the kicking limb decelerated as the shank accelerated at contact, was found in the stage four subjects as

predicted. Although not predicted, an elementary form of the segmental relationship was also found in the stage three subjects.

Significant differences were found in the angular velocity of the shank and angular acceleration of the thigh between stages three and four at contact. Significant differences were also found in the angular velocity of the shank and angular acceleration of the thigh at maximum forward movement of the kicking limb between stages three and four. Although few significant differences were found in the angular velocities and accelerations of the thigh, as well as the shank between stages three and four, observable differences were evident in the graphs of the kicking sequences for selected stage three and four subjects.

Differences between the direct and angled approaches were minimal. Only the angular acceleration of the shank, at contact, was found to be significantly different between stages three and four. This finding was likely due to the increased difficulty of the angled approach, as the angular acceleration of the shank was lower for the angled approach.

The Micro-Soccer ball was found to be significantly different in release than that of the standard youth size three soccer ball. No significant differences were found between the two approaches. If kicking performance is measured by ball velocity, the Micro-Soccer ball did positively improve kicking performance.

DEDICATION

To Mom and Dad.
You taught me to never give up!
and
To Trish, Erik and Beth.
Thank you will never be enough.
I love you.

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Chapter 1

INTRODUCTION

Soccer has been touted as the world's most popular game by countless proponents of the game. As of 1996, in the United States alone, over three million youth under 19 years of age were registered to play soccer (Soccer Industry Council of America, 1996). Soccer is a game of constant movement and adaptation, requiring teamwork and the use of individual skills specific to the game. The individual soccer skills that must be mastered include: dribbling, tackling, receiving, passing, heading, crossing and shooting. For the aspiring soccer player, the development of these skills usually takes place at an early age.

Kicking is an important aspect of the game and the development of an appropriate motor pattern is crucial to success in soccer. Kicking has been described by Wickstrom (1983) as a unique form of striking, in which the foot is used to impart force to a ball. Studying the mechanics of sport specific skills (such as kicking) provides physical educators and coaches with a deeper foundation to effect change in participants. By investigating the kinematics associated with a developmental sequence of kicking, it is possible to quantify previously observed characteristics.

Kicking has been described as a modification of bipedal locomotion by Huang, Roberts and Youm (1982). These investigators differentiated between the locomotion skills of walking and running and the skill of kicking because the primary force production for a kick is from the swinging limb, not the support limb. They also stated that the overall speed of the swinging distal segment was faster in kicking than in either walking or running. The specific sequence and timing of the kick has been determined to be valuable with respect to kicking performance (Putnam, 1983). Specific segmental interactions have been identified in adults, as discussed by Putnam (1991, 1993) and Glassow and Mortimer (1968), but have yet to be identified for the developmental years. The qualitative descriptions by Haubenstricker, Seefeldt, Fountain and Sapp (1981) provided an excellent basis for continuing to examine the skill of kicking. With an increase of 279% in youth soccer participation in the United States since 1980 (Soccer Industry Council, 1996), a demonstrated need for quantitative analyses of the developmental sequence of kicking was highlighted. Quantitative analyses can aid in the evolution and advancement of methods and strategies for teachers and coaches.

There have been numerous studies completed on kicking skills (Haubenstricker et al., 1981), including segmental interactions (Barfield, 1995; Putnam, 1983, 1991 and 1993), muscular strength and coordination (Too and Hoshizaki, 1984), muscle activity during a kick (DeProft, Clarys, Bollens, Cabri and Dufour, 1988), and injuries associated with kicking (Ekstrand and Gillquist, 1983; Nike, 1995). However, to date, few investigators have studied the developmental aspects of kicking in soccer biomechanically (Too and Hoshizaki, 1984; and Luhtanen, 1988).

Statement of the problem

Qualitative descriptions of kicking have been completed by Seefeldt and Haubenstricker (1972) and Haubenstricker et al. (1981). They divided kicking into four stages, or levels, which provide observable milestones during a child's development of the kicking skill. The first two stages did not involve a moving approach to the ball, whereas stages three and four involved a deliberate moving approach to the ball. The stages of development provided teachers and coaches with a basis for improving the level of performance that was age appropriate for children. Although this information was age appropriate, it was not necessarily age dependent. The stages identified by

Haubenstricker et al. (1981) utilized a direct, sagittal plane approach to the ball, which may or may not apply to an angled approach soccer kick.

With increased youth participation in soccer in the United States, a comprehensive understanding of kicking is needed, as children begin to become involved in youth soccer programs as early as four years of age (Soccer Industry Council of America, 1996). Coaches and physical educators need to understand the mechanics involved in kicking in order to utilize correct techniques with children in instructional settings.

Purpose of the study

Investigating the quantitative aspects of the development of kicking is important to an increased understanding of kicking for improved teaching techniques and skill development. Therefore, the purposes of this study were to:

1. Identify selected kinematic variables associated with children exhibiting kicking stages one through four during a direct approach, using a standard size three soccer ball and a newly developed light weight soccer ball.

2. Identify differences in selected kinematic variables associated with children exhibiting kicking stages three and four using direct and angled approaches to the ball, using a standard youth soccer ball and a newly developed lightweight soccer ball.

3. Identify the differences in the resultant ball velocity of a standard youth soccer ball versus a lightweight soccer ball, when kicked by subjects exhibiting stages three and four, for both the direct and angled approaches.

4. Identify the effect of a light weight ball on the motor development of kicking. To date, no investigations have been found in which researchers studied the effects of ball size, ball weight or ball color as these variables relate to kicking performance.

Need for the study

Quantitatively identifying characteristics associated with the development of kicking will enable physical educators and coaches to deepen their understanding of the qualitative descriptions existing in the literature. With this increased understanding of kicking, the methods developed for teaching the skill of kicking will be more effective for the participants. This study also broadened the knowledge base of kicking by identifying the kinematic variables associated with the angled approach soccer kick. The developmental stages of kicking, using the direct approach and angled approach, have not been kinematically quantified for children. By quantifying observed phenomena, it is possible to adapt current paradigms so that physical education teachers and youth sport coaches can be more effective in assessing and improving the kicking performance of children.

Research hypotheses

The current study investigated three major issues. First, this study investigated selected kinematic variables for each of the four developmental stages of kicking using a direct approach to the ball (Haubenstricker et al., 1981). Stage one was identified as the least mature technique and stage four was identified as the most mature technique. Secondly, this study examined differences in the selected kinematic variables in subjects exhibiting stage three and four techniques, while utilizing an angled approach to the ball. Finally, this study investigated the effect ball weight had on the selected kinematic variables for each stage level, the approach used to kick the ball, and resultant ball velocity. The best trial as defined by the identification of foot/ball contact, for each soccer ball, was selected for analysis for all subjects using the direct approach. The best trial as defined by the identification of foot/ball contact, for each soccer ball, was selected for analysis for all subjects using the angled approach.

Kinematic variables

Standard videographic techniques were used to capture primarily sagittal plane motion to obtain the following kinematic data:

1. The angular displacements of the thigh and shank segments at selected points during the kick:
    a. Stages one through four for the direct approach for both the standard size and lightweight balls:
        1) maximum backswing of the kicking leg,
        2) foot and ball contact,
        3) maximum forward movement of the kicking foot after the ball leaves the foot.
    b. Stages three and four for the angled approach for both the standard size and lightweight balls:
        1) maximum backswing of the kicking leg,
        2) foot and ball contact,
        3) maximum forward movement of the kicking foot after the ball leaves the foot.
2. The angular velocities of the thigh and shank segments at selected points during the kick:
    a. Stages one through four for the direct approach for both the standard size and lightweight balls:
        1) maximum backswing of the kicking leg,

2) foot and ball contact,

3) maximum forward movement of the kicking foot after the ball leaves the foot.

b. Stages three and four for the angled approach for both the standard size and lightweight ball:

1) maximum backswing of the kicking leg,

2) foot and ball contact,

3) maximum forward movement of the kicking foot after the ball leaves the foot.

3. The angular accelerations of the thigh and shank segments at selected points during the kick:

a. Stages one through four for the direct approach for both the standard size and light weight balls:

1) maximum backswing of the kicking leg,

2) foot and ball contact,

3) maximum forward movement of the kicking foot after the ball leaves the foot.

b. Stages three and four for the angled approach for both the standard size and light weight balls:

1) maximum backswing of the kicking leg,

2) foot and ball contact,

3) maximum forward movement of the kicking foot after the ball leaves the foot.

4. The resultant ball velocities of both the standard size and light weight soccer balls:

a. Stages one through four using the direct approach.

b. Stages three and four using the angled approach.

The developmental sequences of kicking have been described and validated in the literature (Seefeldt and Haubenstricker, 1972; Haubenstricker et al. ,1981). Based on Seefeldt and Haubenstricker's and Haubenstricker's et al. work, the following developmental trends were predicted for the kicking leg of subjects involved in this study.

Predicted developmental trends (direct approach)

1. Preparatory Phase. Predicted developmental trends for this phase will be:

a. The stage one performer will exhibit no hyperextension of the hip.

b. The stage two performer will exhibit both hyperextension of the hip and knee flexion.

c. The stage three performer will exhibit greater hip hyperextension and knee flexion than stage one and two performers, as a result of a deliberate approach to the ball.

d. A stage four performer will exhibit the greatest hip hyperextension and knee flexion of all stages, as a result of the final approach step being an airborne phase or leap.

2. Force Production Phase (Contact). Predicted developmental trends for this phase will be:

a. The stage one performer will displace the kicking leg forward as a result of hip flexion causing the thigh to be positioned approximately parallel to the ground at ball contact. The knee is flexed prior to and at ball contact.

b. The stage two performer will exhibit an increased angular displacement, velocity and acceleration of the kicking leg, compared to stage one, resulting in increased knee flexion during force production. The stage two performer will exhibit knee flexion at ball contact.

c. The stage three performer will exhibit greater angular displacement, velocity and acceleration of the kicking leg. At contact the knee will be slightly flexed.

d. The stage four performer will exhibit the greatest angular displacements, velocities and accelerations of the kicking leg, and will have full knee extension at ball contact. Additionally, the stage four performer will exhibit the segmental relationship between the thigh and shank, in which the thigh velocity decreases as the shank velocity increases to ball contact.

3. Follow through Phase. Predicted developmental trends for this phase will be:

a. The stage one performers will continue knee extension after ball contact.

b. The stage two performers will continue knee extension after ball contact.

c. The stage three performers will continue knee extension after ball contact. There will be a continuing greater degree of knee extension from stage one to stage three.

d. The stage four performer will have complete knee extension and will be airborne after ball contact.

An overview of the predicted trends for the direct approach were provided in Table 1. The chart of the characteristics also provided the reader a comparison across the four stages.

Table 1

Predicted Trends for the Direct Approach With Both a Standard Youth Soccer Ball and a Micro-Soccer Ball

	Stage 1	Stage 2	Stage 3	Stage 4
Prepartory Phase				
	No hip hyperext.	Hip hyperext. Knee flexion	Step >Hip hyperext. >Knee flexion	Leap or hop >Hip hyperext. >Knee flexion
Force Production				
	Hip flexion Parallel thigh Knee flexion	Shank angular >θ >ω >α	Shank angular >θ >ω >α	Shank angular >θ >ω >α
		Thigh angular >θ >ω >α	Thigh angular >θ >ω >α	Thigh angular >θ >ω >α
		Knee flexion at contact	Slight knee flexion at contact	Soccer paradox Full knee extension
Follow Through	Knee extension	Knee extension	Knee extension	Complete knee extension Airborne

θ = angular displacement
ω = angular velocity
α = angular acceleration

Developmental trends for the gross motor skill of kicking have been presented with subjects exhibiting a direct approach (Seefeldt & Haubenstricker, 1972;

Haubenstricker et al., 1981). However, to date, no literature has been found on the developmental stages of kicking using an angled approach. A stage one or two performer using a direct approach was not expected to be capable of performing an angled approach, since these two stages do not have a deliberate approach to the ball. It was proposed that the use of an angled approach would require performers to exhibit a relatively mature developmental level (stage three or four) of kicking in order to successfully complete a kick utilizing an angled approach. Since stages three and four used a deliberate approach to the ball, it was expected that they could perform an angled approach kick. The performer was required to approach the ball from an angle of 45 degrees rather than from straight behind the ball as in a direct approach.

Predicted developmental trends (angled approach)

Based on the current literature and two preliminary investigations, the author proposed two developmental stages for an angled kick, the Basic Stage and the Mature Stage. The Basic Stage was the elementary level of the angled kick and was expected to be seen in a performer who could exhibit a stage three direct approach kick. Therefore, the stage three subjects were identified as Basic Stage subjects. The Mature Stage was the more advanced stage of the angled kick and therefore, the stage four subjects were identified as Mature Stage subjects. Based on related literature and the extensive soccer background of the author, the following developmental trends were predicted for subjects using an angled approach.

1. Preparatory Phase. Predicted developmental trends for this phase will be:

a. The Basic Stage performers will exhibit hip hyperextension and knee flexion of the kicking leg as a result of a deliberate, angled approach to the ball. The support foot of the non-kicking leg will be directed along the angled approach path.

b. The Mature Stage performers will exhibit a marked increase in hip hyperextension and knee flexion as a result of an airborne leap prior to ball contact. The support foot of the non-kicking leg will be placed parallel to the line of intended direction the ball is to be kicked.

2. Force Production Phase (Contact). Predicted developmental trends for this phase will be:

a. The Basic Stage performers will exhibit an increase in thigh and shank velocity up to ball contact. At ball contact there will be knee flexion as well as hip flexion.

b. The Mature Stage performers will exhibit the relationship between the thigh and shank characterizing the "soccer paradox". With the soccer paradox, the thigh velocity will decrease as the shank increases in velocity. At ball contact the knee will be in a flexed position.

3. Follow Through Phase. Predicted developmental trends for this phase will be:

a. The Basic Stage performers will maintain flexion at the knee joint of the kicking leg.

b. The Mature Stage performers will exhibit marked flexion of the hip accompanied by knee flexion during follow through.

An overview of the predicted trends for the angled approach were listed in Table 2.

Table 2

Predicted Trends for the Angled Approach While Kicking a Standard Youth Soccer Ball and a Micro-Soccer Ball

	Basic Stage	Mature Stage
Preparatory Phase		
	Step	Leap
	Hip hyperext.	>Hip hyperext.
	Knee flexion	>Knee flexion
	Support foot along approach path	Support foot || to intended direction
Force Production		
	Increasing thigh and shank velocity	Thigh velocity decrease
	Hip flexion	Shank velocity increase
	Knee flexion	Knee flexion
Follow Through		
	Knee flexion	>Hip flexion
		Knee flexion

Hypotheses

From the current literature and predicted trends, the following hypotheses were developed. Each of the hypotheses were tested within the context of this study.

1. Each of the kinematic variables will follow the predicted trends as stated.

The kinematic variables include the angular displacements, velocities, and accelerations of the thigh and shank at three distinct positions during the kick. These positions were: a) maximum backswing of the kicking leg, b) foot/ball contact and c) maximum forward movement of the kicking foot after the ball leaves the foot.

These kinematic variables were expected to follow the predicted trends, for each stage of the direct approach and the angled approach as defined for the preparatory, force production (contact), and follow through phases.

2. There will be a difference in the rotations of the thigh, as well as the shank, of the kicking limb between subjects exhibiting stages three and four while using a standard youth soccer ball using a direct approach to the ball. The stage four subjects will exhibit a more mature pattern of the kicking limb than the stage three subjects, as rotation of the thigh will be greater in the initial portion of the force production phase, with minimal rotation of the shank about the knee joint. In the later portion of stage four's force production phase, thigh rotation will decrease as shank rotation increases to ball contact.

3. There will be a difference in the rotations of the thigh, as well as the shank, of the kicking limb of the subjects using a direct approach when compared with subjects using an angled approach, while kicking a standard youth soccer ball.

4. The resultant ball velocity of the light weight soccer ball will be greater than that of the standard youth soccer ball, regardless of approach.

Limitations

The following limitations were identified for this study:

1. The subject's ability to kick the soccer balls forcefully as instructed by the investigator.
2. The ability to see all targets throughout the digitization process. Targets that were hidden by body parts during part of the kick were digitized using a "best guess".

3. The APAS system is capable of filming only at .017 sec/frame. This relatively low speed may cause any fine tuning of data point capture to be missed, since it physically was not captured.

4. The software used by the APAS system. Since the data are stored in binary, the 3-D data points could not be downloaded in order to use our own software programs for calculations. These limitations were discussed at more length in Chapter three.

Definition of terms

Acceleration - The rate of change of velocity.

Anthropometry - Measurements of the human body including the size, shape and weight of body segments.

Displacement - A change in position.

Extension - The movement of a segment, relative to an adjacent segment, in which the angle increases between the segments.

FIFA - The Federation Internationale de Football Association, the world governing body of international soccer.

Flexion - The movement of a segment, relative to an adjacent segment, in which the angle decreases between the segments.

Kinematics - Description of movement including time, displacement, velocity and acceleration.

Soccer instep kick - The type of kick in which a soccer ball is contacted on the instep of the kicking foot (lace area on the shoe).

Support foot - The foot providing support for the body during the kicking action.

Velocity - The rate of change of displacement.

MBS - Maximum backswing. The maximum posterior position of the kicking leg thigh.

FBC - Foot/Ball Contact.

MFM - Maximum forward movement. The maximum height of the kicking leg foot from the floor.

θ (Theta) - Angular displacement. The angular displacement was determined as the angle between two adjacent segments.

ω (Omega) - Angular velocity. $\omega = \Delta\theta / \Delta t$.

α (Alpha) - Angular acceleration. $\alpha = \Delta\omega / \Delta t$.

Chapter 2

REVIEW OF LITERATURE

The purpose of this review was to examine the literature related to selected variables that affect the performance of a soccer kick in children. A major goal of this research was to identify the differences in the kinematic variables associated with the development of kicking in children. Therefore it was necessary to examine the literature pertaining to the developmental and mechanical characteristics of kicking. This information provided a foundation for discussion as it related to the development of kicking in children.

Movement and mechanics

Mechanics is the branch of physics that investigates the influence of forces on bodies and mechanical systems (Hall, 1995). Biomechanics is defined as the science that studies the mechanics of human motion (Hall, 1995). "Motor development is the progressive change in motor behavior throughout the life cycle, brought about by interaction among the requirements of the task, the biology of the individual, and the conditions of the environment" (Gallahue and Ozmun, 1995, p. 3). In combination, it is possible to use biomechanical principles and techniques to study the development of motor skills. It was not the intent of this author to provide an exhaustive review on the discipline of Motor Development but rather an overview to justify quantification of the qualitative analysis of the fundamental motor skill of kicking as reported by Seefeldt and Haubenstricker (1972) and its subsequent validation by Haubenstricker et al. (1981).

Development of motor skills is evidenced by changes in the movement patterns of the skills. It is possible to observe the changes in movement behavior by observing the process (form) and product (performance) (Gallahue and Ozmun, 1995). Observable movements have been grouped into three categories: stabilizing movements, locomotor movements, and manipulative movements. It is likely that some movements may contain a combination of all three categories (Gallahue and Ozmun, 1995). Playing soccer involves all three types of movements, as does kicking a ball. The approach to the ball requires locomotor skill, the contact of the support foot with the ground stabilizes the individual in order to kick (manipulate) the ball. By dividing a motor skill into phases, a foundation for specific sequential descriptions of a motor skill is established.

Qualitative analyses, such as the studies completed by Seefeldt and Haubenstricker (1972) and Haubenstricker et al. (1981) provided information on the process or form of the development of kicking. The use of biomechanical techniques in studying the stages of development can provide a method by which the skill can be quantified and further describe the development of kicking. Biomechanics can provide the physical educator with a means to apply mechanical principles to the analysis of a fundamental motor skill such as kicking. A mechanical analysis of kicking can serve as a standard and make it possible to understand kicking beyond the descriptive level (Wickstrom, 1983). Additionally, it is possible to study the development of kicking as it becomes "biomechanically more efficient" (Wickstrom, 1983, p. 17). A biomechanical analysis of kicking can highlight the relative importance of muscular strength in the development of this fundamental motor skill. Although muscular strength was not a variable studied in the present investigation, it is worthy to note its importance in the development of a motor pattern.

Force is required to produce movement. A component of that force is muscular strength, as well as the coordinated movement for maximum summation of forces. To execute a mature form of a motor skill, the muscles must provide enough force to start, accelerate, stop or change the direction of movement effectively, according to a prescribed pattern (Wickstrom, 1983). A lack of force due to inadequate muscular strength can dictate the form and limit performance. In velocity oriented skills, such as kicking, inadequate muscular strength is manifested in a reduced velocity of the kicking segments or limbs affecting the process, as well as the resultant velocity of the ball or product. "Velocity production is an essential consideration in most fundamental motor skills" (Wickstrom, 1983, p. 18). Other things being equal (i.e., size, weight, strength), a subject exhibiting a stage one kick should exhibit a lower velocity of the swinging (kicking) limb, than a stage four performer. Consequently, a lower velocity of the swinging limb results in a lower resultant velocity of the ball as it comes off the foot.

By using biomechanical procedures it is possible to study the mechanics of kicking and other fundamental motor skills, as was evident in the study by Kiger (1987). The purpose of Kiger's study was to identify specific mechanical differences observed in the development of the skill of running and to identify which specific kinematic variables differed between the stages and between gender. Limited statistical significance was obtained (which could be attributed to a small sample size and p value) in the study for stage effect, but Kiger found developmental trends across the stages. The work by Kiger (1987), and the theories developed by Wickstrom (1983) and Gallahue and Ozmun (1995) influenced the current author's decision to use a biomechanical approach to capture and analyze the data. Subsequent digitization of the data and software useage allowed the data to be quantified. A biomechanical evaluation of the developmental stages of kicking, qualitatively studied by Seefeldt and Haubenstricker (1972) and Haubenstricker et al. (1981), was performed. In addition, the description and quantification of the development of a diagonal kick was performed by the author.

Characteristics of kicking

Kicking is a basic skill that is used in various activities and sports. Kicking has been described as a modification of walking and running (Huang et al., 1982). The main difference between walking, running, and kicking is in the primary force production. During a kick, the force production is in the swinging segment, whereas in walking, force is produced in the support segment. Huang et al.(1982), in a biomechanical analysis, determined that the speed of the swinging segment is significantly faster in a kick than in running. Kicking has been divided into preparatory, force production and follow through phases (Haubenstricker et al., 1981). As a child improves in this particular movement task, an orderly sequential progression of change occurs in movement control. Biomechanically, ball contact is identified as an event that occurs between the end of the force production phase and the beginning of the follow through phase. A specific sequence of movements and timing are requirements for a successful kick. Also, appropriate levels of muscular strength are required to propel an object, such as a soccer ball. A soccer kick using the right leg has been described in the following manner by Douge (1988):

I 45 degree approach with a slight forward lean;

II leg adduction of the kicking leg on the second to last step to cater for trunk rotation;

III explosive final step;

IV externally rotate the non-kicking hip;

V support foot 15-20 cm to the side of the ball, transverse arch crosses an imaginary ball bisection;

VI internally rotate the kicking leg during the kick: Trunk rotation begins simultaneously with kicking leg hip extension and knee flexion;

VII support leg knee eccentric contraction to absorb body weight;

VIII kicking leg knee leads foot to ball;

IX as kicking leg passes over ball, it is forcefully extended and foot plantar flexed; the left arm adducts across the chest to prevent excessive left shoulder rotation and keeps the shoulder parallel to the goal line;

X deceleration by eccentric knee flexion, external rotation, extension and abduction at the hip joint of the kicking leg.

The skill as described above can be difficult for children to execute with a stationary ball, let alone a moving ball, as is often the case in a soccer game. A child trying to kick a ball must appropriately sequence the body segments in order to produce the desired outcome of kicking a ball. Keough and Sugden (1985), explained that children have three general problems they must solve when striking (kicking) an object. First, they must control the sequence of the limb movement. Second, they must direct the limb to a position that will contact the object in the appropriate direction. Thirdly, they must time the sequence to end after impact. Potentially there is a fourth problem of force production modulation. Force production modulation adds a muscular strength component for the child attempting to propel the ball in a specific direction and over a given distance. Therefore, a rather complex combination of coordination and muscular strength is required in performing a successful kick.

A developmental sequence of kicking (Haubenstricker et al., 1981) is helpful in assessing performance qualitatively. The developmental sequence used by the Motor Development Program at Michigan State University (MSU) was divided into four stages with a specific description of the three phases within each stage. The current study determined if the selected kinematic variables of linear and angular displacements, velocities and accelerations differed between the stages, for subjects who used a standard youth soccer ball and a newly developed lightweight ball. The characteristics from Haubenstricker's et al. (1981) developmental sequence of kicking of stage one through four follow:

Stage 1

Preparatory Phase - The performer is usually stationary and positioned near the ball. If the performer moves prior to kicking, the steps are short and concerned with spatial relationships rather than obtaining momentum for the kick.

Force Production - The thigh of the kicking leg moves forward with the knee flexed and is nearly parallel to the surface by the time the foot contacts the ball. Knee joint extension occurs after contact, resulting in pushing rather than a striking action. Upper extremity action is usually bilateral, but may show some opposition in older performers. (If the performer is too far from the ball as the extremity moves to meet the ball the knee flexes only slightly and the leg swings forward from the hip in a pushing action.)

Follow Through Phase - The knee of the kicking leg continues to extend until it approaches 180 degrees. If the trunk is inclined forward following contact with the ball, the performer will step forward to regain balance. If the trunk is leaning backward, the kicking leg will move backward after ball contact to achieve body balance.

Stage 2

Preparatory Phase - The performer is stationary. Initial action involves hyperextension at the hips and flexion at the knee so that the thigh of the kicking leg is behind the mid-frontal plane. The arms may move into position of opposition in situations of extreme hyperextension at the hips.

Force Production Phase - The kicking leg moves forward with the knee joint in a flexed position. Knee joint extension begins just prior to foot contact with the ball. Arm-leg opposition occurs during the kick.

Follow Through Phase - Knee extension continues after the ball leaves the foot, but the force of the kick usually is not sufficient to move the body forward. Instead, the performer usually steps sideward or backward.

Stage 3

Preparatory Phase - The performer takes one or more deliberate steps to approach the ball. The support leg is placed near the ball and slightly to the side of it.

Force Production Phase - The kicking foot stays near the surface as it approaches the ball. The trunk remains nearly upright, thereby preventing maximum force production. The knee begins to extend prior to contact. Arm-leg opposition is evident.

Follow Through Phase - The force of the kick may carry the performer past the point of contact if the approach was vigorous. Otherwise the performer may remain near the point of contact.

Stage 4

Preparatory Phase - The approach involves one or more steps with the final "step" being an airborne run or leap. This permits hyperextension of the hip and flexion of the knee.

Force Production Phase - The shoulders are retracted and the trunk is inclined backward as the supporting leg makes contact with surface and the kicking leg begins to move forward. The movement of the thigh

> nearly stops as the knee joint begins to extend rapidly just prior to contact with the ball. Arm-leg opposition is present, as in the previous two stages.
>
> Follow Through Phase - If the forward momentum of the kick is sufficient, the performer either hops on the support leg or scissors the legs while airborne in order to land on the kicking foot.

The influence of age, gender, balance, and participation in organized soccer programs on the development of kicking by children in grades K - 8 was completed by Butterfield and Loovis (1994). Seven hundred and sixteen boys and girls in grades K-8 were studied. The children were tested individually in kicking performance, static balance, dynamic balance, and were given a survey to determine youth soccer participation. Butterfield and Loovis (1994) reported that boys' kicking performance increased linearly on a yearly basis through grade four, dropped off in grade five, recovered in grade 6, and dropped off in grades seven and eight. The percentage of girls exhibiting a mature pattern was lower than that of the boys, but the development of kicking paralleled the boys' results.

The grade four decrement could have resulted from children choosing other activities to be involved in that did not involve kicking. Gallahue (1982) has termed grade four a "sport-related" stage of motor development. It is this age when children begin to increase their involvement in specific sports.

Participation in organized soccer did not influence the development of a mature kicking pattern (Butterfield and Loovis, 1994). It was hypothesized that youth sports programs may provide excellent sources of exercise but do not influence skill development. Butterfield and Loovis (1994) indicated that some children do not develop a mature pattern even by grade eight. This trend highlighted the need to continue emphasizing skill development, as well as encouraging participation in youth sports.

Putnam (1983) examined the interaction between the thigh and shank during a punt kick. Putnam determined that the motion of the thigh influenced the shank by angularly accelerating it in the positive direction during the kick. During the initial phase of a kick, the thigh dominated, with little rotation of the shank relative to the thigh. During the remainder of the kick, the rotation of the thigh decreased rapidly while rotation of the shank increased. This relationship was important in analyzing a kick. A decrease in thigh rotation has been seen in skilled kickers (Barfield, 1995; Putnam, 1983 and 1991; Too and Hoshizaki, 1984; Plagenhoef, 1971) and was qualitatively described in the stage four of the MSU developmental sequence (Haubenstricker et al., 1981). Too and Hoshizaki (1984) and Plagenhoef (1971) also determined that there was a sequenced relationship evident in skilled performers.

Sequence and coordination of segments

The body segments involved in kicking can be modeled as an open-linked system (Huang et al., 1988; Putnam, 1993), where the segments are rigid bodies of which the distal segment moves freely through space. In a kick, the most distal end of the system is used to impact an object. The sequence of the kicking motion can be characterized as progressing from proximal to distal (Putnam, 1983, 1991 and 1993; Haubenstricker et al, 1981; Plagenhoef, 1971).

Bunn (1972) stated that to maximize the speed at the distal end of a linked system, the movement should start with the more proximal segment and progress to the more distal segments. Each distal segment then starts its motion at the instant of greatest speed of the preceding segment. This movement has been called the summation of speed and summation of forces principle. According to Putnam (1993) the summation of forces principle was of limited value in describing a kick because of the lack of mechanical explanation. The use of the summation of forces principle suggested that at the end of the movement, the speed of the distal end of the segment would have reached its maximal linear and angular velocities at impact. Putnam stated that a segment's endpoint resultant movement did not explain the relative contributions of that segment. Plagenhoef (1971) also utilized the summation of forces principle to determine a resultant linear velocity in describing kicking performance.

Putnam (1993) compared the summation of speed principle, the use of joint angular velocity, and the use of segment angular velocity while describing a kick. She described the use of joint angular velocity as most valuable when examining the most proximal segment participating in the sequence, and the angular velocities of the joints as most valuable when looking at the proximal ends of the remaining segments. Putnam (1993) suggested that the use of joint angular velocities would be useful in visually describing the motion of a kick.

The use of segment angular velocity data provided information to describe what caused the motion of each segment of a kick (Putnam,1993). Putnam (1993) stated that using segment angular velocities required knowledge of segment orientations, segment angular accelerations and linear accelerations of the proximal end of the linked system. Putnam also suggested that if one looked only at the distal segment's maximum speed, one would sense that all the joints involved during a kick would be fully extended and the angular rotations of the segments would be the same at the moment of impact.

Angular rotations of the thigh and shank segments were not the same at impact in a soccer kick (Barfield, 1993; Putnam, 1983; Luthanen, 1988; Isokaw and Lees, 1988). It has been determined that the angular rotation of the thigh was greater than that of the shank during the force production phase of a kick. In actuality, as hip flexion began the shank was rotating backward relative to the thigh. The backward rotation of the shank resulted in flexion of the knee. As the kick progressed, the rotation of the thigh decreased, while the forward rotation of the shank increased as described by Putnam (1983). The decrease in the thigh's angular velocity did not result in acceleration of the shank, but rather the decrease in thigh angular velocity was the result of the shank's angular motion on the thigh according to Putnam (1983).

As a result of practice there are changes in the movement pattern of a soccer kick that can be kinematically observed (Anderson and Sidaway, 1994). Anderson and Sidaway (1994) examined the changes in coordination that resulted from practicing a soccer kick by college age subjects. Their hypothesis was that the subjects would initially simplify the control of the movement by limiting the range of motion of the hip and knee joints. They also predicted that over time, and with supervised practice, the limitations on the range of motion would be removed. The subjects in the study were told that their primary purpose was to try to maximize the ball velocity while hitting the target area. Paired *t* tests were used to compare pre- to post practice results in the dependent variables. The dependent variables, of interest to the current study, were maximum linear foot velocity, maximum hip and knee angular velocity, and joint range of motion at the hip and knee between the maximum and minimum angles at each joint. According to Anderson and Sidaway (1994), all of the dependent variables of the study were related to performance. Additionally, the authors determined there was an increase in performance as a result of practice.

Kinematics and kinetics of kicking

Literature pertaining to the kinematic and kinetic variables of kicking has been primarily concerned with resultant ball velocity as the measure of kicking performance, with the majority of these studies using adults as subjects (Abo-Abdo, 1981; Barfield, 1995). A study by Too and Hoshizaki (1984) investigated the contribution of strength and coordination patterns to kicking performance. Too and Hoshizaki (1984) used two mini-soccer balls weighing 347 and 349 grams, for the 9-12 year-old subjects. The effect of the mini-soccer ball on mechanical variables of the kick was not determined. Too and Hoshizaki (1984) studied the relationship between isokinetic quadriceps leg strength and ball angle projection, ball lateral deviation, and kicking leg movement patterns on maximal distance a ball was kicked. The study involved subjects 9-17 years of age. The subjects were divided into three age groups: 9-12 years, 13-15 years and 16-17 years. The 9-12 year old group used a mini-soccer ball, whereas the other two groups used a standard size five ball. The results of Too and Hoshizaki (1984) indicated that ball angle of projection varied the most for the 9-12 year old group, relative to the three groups. The 13-15 year old group had the greatest variation in linear ball velocity, while the 16-17 year old group varied in isokinetic impulse at 30 degrees/sec, relative to the three groups . The authors indicated that all of the subjects had mature kicking patterns, as exhibited in a decrease in thigh angular velocity with a corresponding increase in shank velocity prior to ball-foot contact. Too and Hoshizaki stated that foot velocity at impact was related to leg strength and direction applied through the ball was related to motor coordination. Too and Hoshizaki suggested that strength training was more important for the 13-17 years of age group, whereas for the 9-12 years of age group, proper technique should be emphasized.

Resultant ball velocity has been used by many investigators to measure the performance level of subjects completing a kick. The velocity of the ball provided the researcher with a measure of the product of the process of kicking. Luhtanen (1988) investigated resultant ball velocity during a maximal instep kick in soccer players 9-18 years of age. The authors examined the resultant forces and their moments at the hip, knee and ankle joint of the kicking leg as determined from 2-D cinematography and subsequent calculations. Ground reaction forces of the support leg were also determined. The subjects in the study were divided into three groups (9-11, 12-14 and 15-18 years of age). Ball velocities obtained for each group during the study were 14.9, 18.4 and 22.2 m/sec respectively. A one-way ANOVA was used to assess differences between the groups in angular velocity and acceleration of the thigh and shank. Angular velocity and acceleration were determined to be significantly different between the groups, whereas timing and maximum angular velocity were not, also assessed via a one-way ANOVA.

There were minimal differences in the patterns for the three groups. Luhtanen (1988) indicated that the primary difference between the groups was in the magnitude of force production. A 450 gram ball was used for all subjects in Luhtanen's study. The specific weights and dimensions of soccer balls were discussed later in this chapter.

Few studies have investigated the kinematics and kinetics of a soccer kick in children (Luhtanen, 1988; Too and Hoshizaki, 1988). Therefore it was necessary to review literature pertaining to older subjects completing a soccer kick in order to fully understand current theories.

The sequence or timing of the segments is valuable in assessing the performance of a kick, regardless of the type of kick that is performed (Putnam, 1983). Muewssen and Tant (1992) studied the timing, sequence, and interaction of the segments of the leg associated with the soccer instep kick used during low drive, high drive, and maximum distance kicks in college age men. The resultant ball velocities were 21.17, 14.14 and 21.15 m/sec, respectively. Muewssen and Tant (1992) determined that pelvic rotation, hip flexion and extension, and knee flexion and extension were greatest during the high drive kick. The maximum distance and low drive kicks resulted in the greatest hip abduction/adduction. The temporal pattern of the three kicks were very similar. Differences in maximum angular velocity of the lower leg were determined to be significant between the high drive and maximum distance kicks. Muewssen and Tant determined that the pelvis and the thigh moved forward as the lower leg began its posterior rotation. Prior to ball contact, the pelvis and thigh decreased in velocity as the lower leg increased in velocity. No significant differences were found between the angular velocities of the segments during each of the three kicks. Significance was found between the maximum angular velocity of the lower leg and the high drive and maximum distance kicks. The authors concluded that the timing between the three types of kicks were similar, providing evidence that hip abduction/adduction and maximum angular velocity of the lower leg were related to ball velocity.

The ability to kick equally well with the dominant and non-dominant limb is also an important quality for a soccer player. Barfield (1995) studied the kinematic and kinetic differences between dominant and non-dominant limbs during a soccer in-step kick. Barfield found significant differences between limbs of college-age varsity soccer players. Barfield isolated the period of support foot contact through ball contact of the striking limb for analysis. The study correlated maximum ball velocity with kinematic and kinetic variables obtained. The kinematic variables that were found to be highly correlated were: maximum linear velocity of the toe, linear velocity of the toe at ball contact, linear velocity of the ankle at ball contact, mean value from support foot contact to ball contact for linear velocity of the toe and mean value from support foot contact to ball contact for linear acceleration of the knee. Barfield (1995) pointed out that although angular velocity of the knee did not correlate with ball velocity, maximum angular velocity of the knee did occur approximately at ball contact in the dominant limb. However, maximum angular velocity of the knee did not occur at contact, rather it occurred following contact for the non-dominant limb.

The angle at which a ball is approached during a kick has an influence on ball velocity. An approach angle of 30 to 60 degrees produced the greatest ball velocity (Isokaw and Lees, 1988). Plagenhoef (1971) also showed that the approach angle was significant in maximum ball velocity. The study by Isokaw and Lees (1988) determined kinematic and kinetic variables with approach angles to the ball from zero to 90 degrees. The study used a one step approach, in contrast to the two step approach used in Barfield's (1995) study. The differences in a kick with a one step approach and two step kick have not been specifically studied. Isokaw and Lees (1988) did state: "There might be two kicking patterns in the performance of the instep kick with one step."(p. 454) This statement may be a factor when applying the data of Isokawa and Lees to studies using a two step approach, as different patterns of movement may exist during different types of approaches and kicks. The importance of an angled approach can be qualitatively appreciated while watching college or professional football place kickers, as the straight on toe kick is rarely seen.

A 45 degree approach angle to the ball was found to be optimal for maximizing ball velocity (Isokawa & Lees ,1988). Also, an approach angle of 45 to 60 degrees balanced the body's motion, due to the active torque produced during the kicking movement. They suggested that an angled approach may reduce injury by reducing the torque applied to the support foot, and thereby to the ankle and knee.

The type of approach to the ball is an important variable in a soccer kick. Opavsky (1988) studied a standing and a running approach to the soccer kick. The study was a descriptive study of the linear and angular kinematics of the foot, lower leg, upper leg, combined lower leg and foot, and the whole leg. The data presented were consistent with those of Barfield (1995) and Isokaw and Lees (1988). Opavsky (1988) did theorize that the standing kick required more muscular force than the running kick, a result of factoring out the body's momentum. Maximum ball velocity was reported to be 23.48 m/sec for the standing kick and 30.78 m/sec for the running approach. These velocities should not be surprising, since during a running kick a subject could benefit from the body's momentum of the kicking system.

Variability in skill level is evident across age and gender (Butterfield and Loovis, 1994). Consistency in performance, related to both process and product, is crucial for elite performance and is desired at all levels of competition. Phillips (1985) studied the variance exhibited between two kickers. One subject was a place kicker for a professional football team and the other subject, a club level soccer player. The club player exhibited more variability across trials than did the place kicker. Two issues were raised with Phillips' study. First, the study should have used two place kickers or two soccer players. One would expect differences to exist between a place kicker and a soccer player. Kicking a soccer ball during a soccer match is variable, and highly dependent upon the situation. Secondly, place kickers are instructed to kick the ball in the same manner regardless of the distance. It is to be expected that the place kicker's approach to the ball is more consistent than that of the soccer player. Studying invariance of elite kicking performance may be more effectively studied by using similar subjects.

There is a gradual increase in the segmental velocity as a kick moves through its phases (Plagenhoef, 1971; Robertson & Mosher, 1983). As a kick progresses, the initial acceleration is caused by hip flexors and deceleration is caused by the eccentric contraction of the hip extensors (Roberston & Mosher, 1983). This work by Roberston and Mosher supported the summation of muscle forces theory.

The specific sequences of kicking have been modeled, and specific variables have been determined to describe those sequences (Putnam, 1991). Putnam examined the interactive moments, resultant joint moments, and net moments during kicking, walking, and running, as determined from high speed film data and subsequent biomechanical analyses. The discussion of resultant joint moments further explained observed segment motions. Putnam did not agree with Robertson and Mosher (1983) who used the summation of force principle to explain a kick. According to Putnam (1991), there was no evidence that the forward swinging of the lower leg of a kick was initiated by the larger muscles and continued by smaller muscles. Putnam (1991) stated: "changes in the motion of any one segment within a system of linked segments cannot be attributed solely to the muscle forces acting on that segment"(p. 140). The relationship of the muscle forces and the segment motion was dependent upon the interaction between adjacent segments. This relationship aids in explaining that a proximal-to-distal sequence may not always follow a summation of muscle forces. Putnam (1991) discussed the role the muscles play in producing sequential motion as difficult. The resultant joint moments contributed to the net moments of the segments, counteracting the interactive moments. This relationship was seen during the slowing of the thigh velocity as the lower leg extended at the knee to make ball contact. Putnam did not quantify the role of the muscles because of the non-linear relationship between the resultant joint moments and the segment motions.

Zernicke and Roberts (1978) completed a study on leg forces and torques during a kick. They found that during fast kicks, hip torques were small during the later phases of the activity which supported Putnam's (1991) work. The study highlighted the fact that hip extensor moments either were not present or were small. The minimal magnitude of the hip extensor moments helped to explain the influence of the shank on the motion of the thigh, as the shank's movement forward caused the thigh to rotate backward.

Muscular strength and kicking

The relationship between muscular strength and human performance has been investigated in most sports and has been found to be somewhat controversial. These findings are also true for the soccer kick. Some theorists believed that muscular strength training was critical to improved kicking performance (Cabri, DeProft, Dufour & Clarys, 1988; DeProft, Cabri, Dufour & Clarys, 1988; Narici, Sirtori & Mognoni, 1988) as measured by maximum ball velocity and maximum distance kicked; while others placed emphasis on technical development (McLean & Tumilty, 1993). When the component of accuracy was added, muscular strength may not have been the primary factor in performance (McLean & Tumilty, 1993). No studies have been completed investigating the relationship of muscular strength and kicking development in children. Strength has been suggested as a prerequisite for kicking a ball forcefully in adults. Strength could be a factor in skill development in children but that determination was beyond the scope of the current study. It was noteworthy to review the relationship between strength and kicking in older subjects to provide a foundation for discussion as it related to the current study.

Leg strength has been shown to be an important contributor to the development of a kick, as well as to resultant ball velocity in a soccer kick. Narici et al. (1988) studied the relationship between isokinetic strength of the knee extensor and hip flexor muscles and ball velocity during a forceful soccer kick. Adult soccer players and non-soccer players were used in the study. Narici et al. (1988) examined the isokinetic torques of the knee and hip at the nearest possible angular speed to that of kicking. Narici et al. (1988) used a starting knee angle of 150 degrees rather than the standard 90 degrees. Also, 210 degrees versus the standard 180 degrees was used for the starting hip angle. Hip flexion was tested at 180 degrees/sec, and knee extension was tested at 300 degrees/sec. The modification of the starting angles was used in order to maximize the subject's segment velocities. No statistical differences were discovered between dominant and non-dominant limbs. However, high correlations were found between maximal ball velocity and isokinetic strength of the hip flexor and knee extensor muscles in the soccer players. Narici et al. (1988) concluded that the hip flexors play a more important role than the knee extensors, therefore strength training should emphasize the hip flexors of soccer players.

Not only has isokinetic leg strength been shown to be related to resultant ball velocity, other variables involving power have been shown to be related to kicking performance. Cabri et al. (1988) measured isokinetic strength of knee flexion, hip flexion, and hip extension. Subjects were also evaluated on explosive power by the vertical jump, standing jump and triple jump. The performance parameter of Cabri et al. (1988) was the ability to kick a ball a maximum distance. The study compared soccer players and non-soccer players. No description of the non-soccer players was given. Soccer players were determined to be stronger than the non-soccer players across the isokinetic variables and were able to kick the ball farther than the non-soccer players. Kick performance was highly correlated with eccentric knee flexion, eccentric hip extension, and the jump and reach test. Cabri et al. (1988) concluded soccer players demonstrated greater kick performance because of technical skills and more efficient use of their muscular system. The authors also stated that the correlations with kick performance, and eccentric strength of the hamstring group resulted in an improved level of performance as exhibited in an increase of the distance a ball is kicked. The eccentric activation of the antagonistic group supports the "soccer paradox" discussed by DeProft et al. (1988). Cabri et al. (1988) recommended eccentric strength training of the hamstring group during soccer training in addition to general strength training. Of interest to the current author would be an analysis between soccer players and non-soccer players of equal strength. A study between soccer players and non-soccer players may yield different results and bring to the forefront technique as discussed by McLean and Tumilty (1993). As a result of a study by Cabri et al. (1988), it was hypothesized that strength training could be effective in increasing kicking performance.

The effects of strength training have been accepted as a valuable means of improving performance in most sports. DeProft et al. (1988) studied a season long strength training program on kick performance. The subjects were adult soccer players (20 +/- 1.1 years old) and junior soccer players (15.5 +/-0.7 years old). Subjects were divided into a strength training group and a control group. The strength training group received a strength training regime of multiple repetitions at 80 percent maximum effort of different leg muscles (specific exercises were not reported), in addition to regular soccer training (soccer practice). The subjects involved in strength training showed greater strength increases, as well as increases in kick performance. The non-strength training group showed no increase in kick performance. Strength and kick performance correlated only in the strength training group. The strength training group increased 77 percent in eccentric knee flexor strength and 25 percent in concentric knee flexor strength. The hip flexors increased in strength by 15 percent and 35 percent, respectively. DeProft et al. (1988) suggested regular soccer training will improve strength, but adding strength training to routine soccer training would result in increased performance. A point mentioned briefly by DeProft et al. was technique. An in-depth discussion of how technique may relate to performance was not included in the study.

Technique appears to be an important variable in kicking performance. McLean and Tumilty (1993) studied right and left leg asymmetry during a drive and chip kick. The drive kick was characterized as a low trajectory, high velocity kick to a target area. The chip kick was characterized as a lofted kick to a target area. McLean and Tumilty (1993) included accuracy in investigating kick performance by requiring that the subjects kick balls to specific target areas. They also compared isokinetic knee strength with kick performance. The subjects exhibited better performance with the right limb during a drive kick, while no differences were present between limbs during a chip kick. The subjects also had greater strength on the right side.

Studies have reported that isokinetic leg strength is related to kick performance, but other variables, such as technique, may be of greater importance if related to final ball velocity (McLean & Tumilty, 1993). McLean and Tumilty study determined that the drive kick on the right limb (dominant) had a higher velocity (79 km/h) than the chip (66 km/h), but there were no significant differences between the drive (66 km/h) and chip (64 km/h) kicks for the left limb (non-dominant). Correlations resulted in no significant relationship between isokinetic knee strength and kick velocity for either the right or left limb. The left limb velocities were similar for both the drive and chip.

The ball

Biomechanical relationships exist within specific sequences and patterns of a kick. Very few studies have investigated the type of ball used in soccer. As of this writing, no studies published have included the effect of ball size or its weight on soccer kick performance. One study in this review of literature used a smaller ball for its younger subjects (Too and Hoshizaki, 1984), however the researchers did not determine if their results were attributable to the smaller ball. The balls used by the 9-12 year old subjects in Too and Hoshizaki's (1984) study were 347 and 349 grams (12.15 and 12.22 ounces). The study of junior soccer players (9 to 18 years old) by Luhtanen (1988) did not use a smaller ball. The ball used in that study was a size 5 (450 grams, 15.75 ounces).

The Federation of Internationale de Football Association (FIFA) Laws of the Game (1996) dictate that an official ball (size 5) shall not be more than 28 inches (71 cm) and not less than 27 inches (68 cm) in circumference. The weight shall not be more than 16 ounces (453 grams) or less than 14 ounces (396 grams). In the FIFA Laws of the Game, it is permissible, with agreement of the national association involved, to modify the size, weight and material of the ball for players under age 16, for women, and for veterans (over 35). Most sanctioned youth programs in the United States do use smaller and lighter balls for youth. Sanctioned leagues for players under 16 use either a size three or size four ball. Specific size and weights of balls are variable depending upon manufacturer. As millions of youths play soccer world wide, the implications of the development of appropriate size and weight balls for children are apparent.

Youth and less experienced players may be at a higher risk of injury during a soccer match because of the types of balls used. Levendusky, Armstrong, Eck and Jeziorowshi (1988) dropped standard soccer balls on a force plate from 18.09 meters, which resulted in a ball velocity of 17 to 18 m/sec. Peak force and impulse data were collected from this force plate. The mean mass of the stitched balls were 437.7 grams (size 5; FIFA rules specify 396 to 453 grams). These balls produced a mean peak force of 912 N and a mean impulse of 13.72 NS. Peak forces of 670 to 1100 N have been determined to cause head or face injury. As stated in Levendusky et al. (1988), the peak force and impulse were of a magnitude (912 N) to produce injury to the face and head. Junior players (9-11 years old) have been shown to produce mean ball velocities of 14.9 +/- 1.7 m/sec with a 450 gram ball (Luhtanen, 1988). Levedusky et al. (1988) described peak force as a function of ball mass and velocity. Suggestions were made to increase technical training and limit heading for at risk populations. No recommendations were made to reduce the size and weight of the ball, which is within the Laws of the Game (FIFA, 1996). The reduction in ball size and weight, potentially would allow for technical training to occur as well as increased safety.

An additional concern is water retention of the ball, resulting in an increase of the ball's mass. Impact intensity increases as a soccer ball retains water. Armstrong, Levendusky, Eck, Spyropulus and Kugler (1988) investigated the effects of ball wetness and inflation on impact intensity. The soccer balls used in the study were size five. Two recommendations were made. First, manufacturers should develop better water repellent characteristics for ball coverings. Secondly, it was suggested that children and inexperienced adults not participate in soccer under conditions that promote water retention in the ball.

Although the impact studies reviewed were specific to head injuries, inferences can be made to the use of a light weight ball during a kick. If children used a light weight ball, less force would be required to propel the ball. Potentially, requiring less force to kick a ball might result in a change of the specific kicking pattern and result in an increase in performance as measured by ball velocity. The increase in performance may be qualitatively assessed using the MSU Developmental Sequence of Kicking (Haubenstricker et al., 1981) and quantitatively by assessing ball velocity.

Summary of related literature

The biomechanical literature pertaining to the world's most popular game is prevalent. The literature covers many aspects of the game, including strength, muscle type, muscle activation, experience, angle of approach, ball type, sequencing and timing. However, limited literature is available examining youth soccer and kicking. To date no published studies were found that pertain to the specific kinematic variables associated with the development of kicking while using a direct or angled approach to the ball. The proposed study adds to the body of knowledge in the sport of soccer and will assist in the development of age appropriate teaching methods. The continued development of specific strategies and pedagogy may improve methods for training, teaching, coaching and injury prevention of youth soccer participants.

Chapter 3

METHODS AND PROCEDURES

The purpose of this study was to identify the differences in the selected kinematic variables of angular displacements, velocities, and accelerations associated with children exhibiting kicking stages one through four. Two different-sized balls, a standard size three soccer ball and a newly developed Micro-Soccer ball, were used. In addition, two approaches were analyzed: a direct approach and an angled approach to the ball. The best trial for each condition was used for each subject. The selected kinematic variables mentioned above were analyzed and evaluations performed. A comparison of the timing of thigh and shank movements for stages three and four performers was made for both approaches and both soccer balls. Approval of subject selection and testing procedures was obtained from the University Committee on Research Involving Human Subjects at Michigan State University prior to the beginning of the study.

The procedures for the collection and analysis of the data obtained in this study are described in this chapter. Biomechanical sampling methods used in this study were consistent with current biomechanical research. Two preliminary investigations were completed in order to establish the specific procedures used in this study.

Sample

Each potential subject and his or her legal guardian(s) were informed of the nature of the study by the primary investigator or a trained assistant investigator and were asked to sign an informed consent (Appendix A) prior to participation in the study.

Subjects selected for participation in this study were identified as "model" or "classic" examples of one of the four developmental stages of kicking (Haubenstricker et al., 1981). All subjects exhibited the classic characteristics of one of the four stages of kicking during a pre-test kicking period. Only children who were right foot dominant were recruited in order to standardize the biomechanical data collection procedures and establish a homogeneous subject pool. The identification and assignment of each subject's stage level were completed by three researchers prior to testing. These researchers were trained in the Michigan State University developmental sequences of selected skills, including kicking. For the current study, the researchers evaluated each subject independently and agreed upon the classification of study participants. The agreement reached by the three researchers increased the validity and reliability of subject classification.

A total of 20 children, recruited from the Grand Rapids, Michigan area and ranging in age from two to eight years, participated in the current study. This age range was selected because of developmental considerations and subject availability, especially in recruiting children exhibiting patterns associated with stages one and two. According to the study by Seefeldt and Haubenstricker (1971), 60 percent of boys (girls) have reached stage one by age two (age two), stage two by age three (age three and a half), stage three by age four and a half (age six), and stage four by age seven (age seven and a half).

Subjects were assigned to developmental groups based on the classic stages as follows: two each were at stages one and two, and eight subjects each at stages three and four (see Table 3). According to Cohen's rule to estimate sample size (Rothstein, 1985), it was determined that a minimum of seven subjects per group was required for meaningful statistical analysis. The use of eight subjects in the two higher skilled groups increased the power of the statistical tests.

Table 3

Sample Population

Stage	N
1	2
2	2
3	8
4	8

Two soccer ball sizes were used in this study: a standard youth size three ball and a newly developed Micro-Soccer ball. Nationally sanctioned leagues generally use a size three ball for the five-to-eight-year old age group. Additionally, the Micro-Soccer curriculum was designed for five to eight year old participants and resulted in the development of the Micro-Soccer ball. Because of the different weights and sizes (circumferences) of the two balls (Size 3: 337.69 gm, 60.0 cm., and Micro-Soccer ball: 260.93 gm, 64.5 cm), a comparison was made of resultant ball velocities for each ball and for each approach used by the subjects exhibiting stages three and four of kicking.

Subject preparation

Subjects wore a T-shirt, shorts and either flat soled tennis shoes or indoor soccer shoes. Black knit shorts, specifically designed for this study were worn by each subject. The shorts were designed to maximize subject coverage as well as allow for marking the superior iliac spine and greater trochanter with targets directly on the skin. The right side of the shorts were fashioned with a Y-shaped cut to allow for the specific anatomical landmarks to be targeted and then closed around each target (Figure 1). During preliminary testing, using these specifically designed shorts allowed the researcher to identify, mark, and digitize all landmarks without difficulty. Moreover, the shorts provided an excellent contrast to the pelvic and hip markers for the purpose of digitizing.

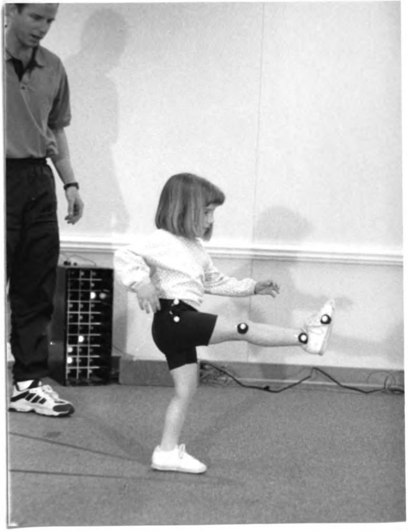

Figure 1. Test shorts.

Each subject had selected landmarks on the right side of the body located, marked, and targeted by the primary investigator. The marker used was a water soluble ink pen. The primary investigator targeted the following landmarks: the fifth metatarsal (shoe location), lateral malleolus, point between the lateral condyle of the tibia and the lateral epicondyle of the femur, greater trochanter, and the superior iliac spine (Figure 2). The targets were spherical forms covered with highly reflective tape. These targets were applied to the subject's skin with double sided hypo-allergenic tape. The targets provided landmarks for digitization for the subsequent determination of angular displacements, velocities and accelerations.

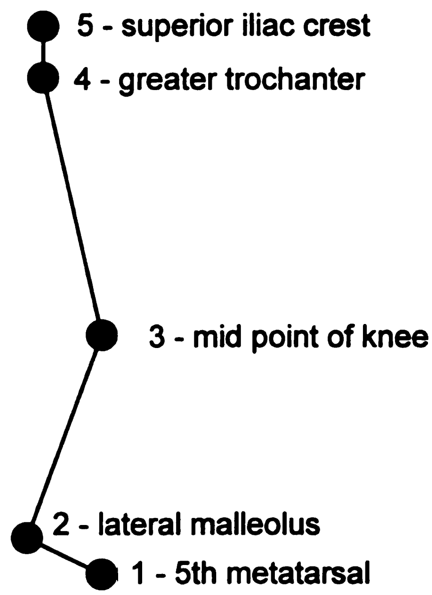

Figure 2. Target locations and order of digitization.

Anthropometric measurements

The subjects had their weight, height, total leg length, femur length, shank length, foot height (with shoes), and foot length measured by the primary investigator following standard anthropometric procedures (Seefeldt, Haubenstricker, Brown, and Branta, 1983).

These measurements were taken after each subject's leg was marked and prior to the subject being targeted.

Inherent problems and accuracy of A.P.A.S.

Several shortcomings are inherent to any videographic system. The limitation with perhaps the greatest potential for affecting any movement study is the speed of the recording device. Normal speed of videographic recordings are too slow for recording ballistic activities often found in sport. The A.P.A.S. runs at a rate of 60 Hz, or .017 sec/frame. Even if shutter speed were set at 1/1000 sec., as was done in the current study, shutter speed affects only the clarity with which one can view the activity, not the physical speed of the videotape. Critical points in a skill could be missed while the shutter is closed.

Zoom lens use is also helpful to reduce the distance the cameras have to be placed away from the object, while maintaining relatively large object to frame size ratio. Determining appropriate object space size is critical to any study as it allows the joint markers to be seen more easily for digitization purposes if the largest object to frame size is used. Approximate object size is determined by the activity being filmed and the size of the calibration structure used. As a result of preliminary testing, it was determined that a 180 cm (length), 120 cm (width), and 90 cm (height) area be calibrated. It was determined that this area was sufficient to capture the full kicking sequence of the children used in this study.

Camera placement and number of cameras used are important parameters to any biomechanical study. Direct linear transformation (D.L.T.) accuracy is dependent on the accuracy of calibration. The calibration structure is used to define a volume in space in order to know locations of points within that volume. Evenly distributed control points covering at least total object space assists in D.L.T. Since D.L.T. residuals are not given by the A.P.A.S. system as in other systems, the calibration must be exact. Specific details on camera placement and calibration procedures are mentioned in subsequent sections.

The accuracy of the A.P.A.S. system has been calculated by several researchers. Ball (Ulibarri personal communication, 1996) found less than one percent error in angular displacement measures with this system. Klein and DeHaven (1995) reported that point estimates were within acceptable range at less than 3.5mm. They stressed that this level of accuracy was consistent with other comparable systems. In this same article, they reported that angular measures were within acceptable limits of less than .3 degrees. Klein and DeHaven (1995) and Vander Linden, Carlson and Hubbard (1992) reported that the greatest estimated angular error was observed as the angle reached 180^0 in most systems, due to the manner in which angles are calculated by the systems. In order to deal with this internal software problem using the A.P.A.S. system, if the angle approaches 180^0, the relationship of segment angles should be used, rather than the joint angle calculations found in the modules. Similar findings were discussed in an unpublished study by Ulibarri and Angeli (1996). Furthermore, they cautioned that an additional minimal error of 1.22% was added by data smoothing. The smoothing technique desired must be given careful consideration in order to minimize the amount of error possible. Cubic spline smoothing was the technique which added the least amount of error to the determined measurements in their study. A priori knowledge of data trends and how each smoothing technique addresses the data are paramount in reducing error due to smoothing. Therefore, the cubic spline method of smoothing was utilized in the current study. With this information in mind, the data collection setup and procedures are explained in the following section.

Data collection procedures

Testing took place in a lab/classroom at Cornerstone College, Grand Rapids, Michigan. The testing sessions were closed except to the subjects, parents of subjects, assistant investigators, and the primary investigator. Closing the sessions prevented curious bystanders from observing and decreased potential stage fright of the subjects. The lab/classroom was decorated with cartoon characters to provide a festive atmosphere for the children. Additionally, the small size of the classroom was selected to reduce stage fright that may have occurred in a larger gymnasium setting. Based on results from a pilot study, the subjects were scheduled in 45-minute time blocks throughout the two days of data collection.

Reference frame

Prior to the subjects' arrival, a calibration structure (Figure 3) which surrounded the area in which the kick was to be performed was set up and incorporated evenly distributed control points to improve accuracy in D.L.T. calculations. The purpose of this calibration structure is to define the location of points in space in order that a volume of space be defined. The calibration structure consisted of 16 control points. Four sets of retro-reflective tape covered balls were strung by surveyor's cord and tension was placed on the cords by surveyor's plumb bobs. The structure defined a calibration space of 120 cm wide by 180 cm long by 90 cm high. The control points were symmetrically distributed and placed 90 cm, 60 cm, 30 cm and 16 cm from the floor. These control points were digitized in the order indicated on the calibration structure in Figure 3. The calibration structure was filmed and then removed from the filming area. Tape marks which had been placed under the plumb bobs were left on the floor to mark the floor space of the calibration volume.

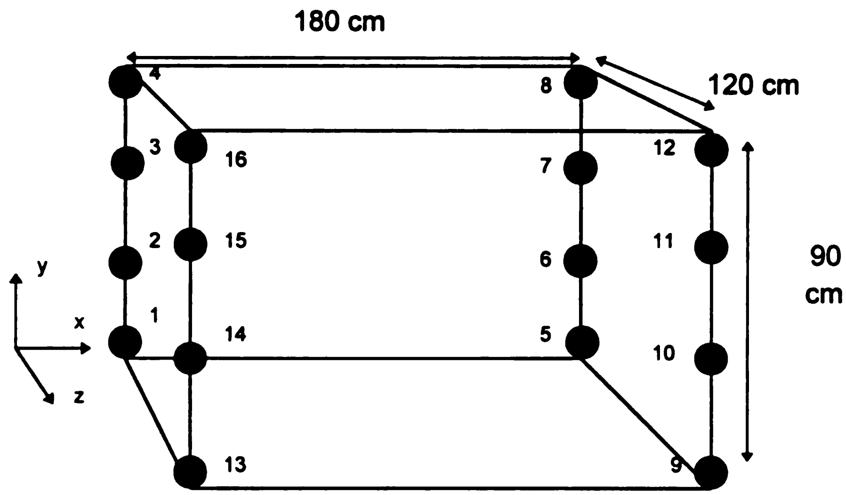

Figure 3. Calibration structure.

Two S-VHS cameras (Panasonic S-VHS Reporter, AG-455) were used to record the trials. The cameras were set to film each trial at 60 frames per second (frame time = .017 sec) and had a shutter speed of 1/1000 second as determined during preliminary testing. Both cameras were equipped with zoom lenses. Each camera was mounted on a tripod and was operated by a trained assistant during the actual filming of subjects. Prior to subject filming, the zoom lenses were focused in on the calibration structure so that all control points were visible with the largest possible image in the frame. This allowed the largest object to frame size ratio which helped decrease error in digitization because the markers were as large as possible relative to the calibration space. The cameras were placed at an angle of approximately 60 degrees to each other, in the sagittal plane, to the right side of each subject's kick. Camera one was to the right and slightly to the rear of the soccer ball placement and camera two was located to the right and slightly forward of the soccer ball placement. The camera placement allowed for all targets to be in the field of view for each camera. Timing lights were placed in the field of view of both cameras for synchronization of frames during data reduction. An eight millimeter Sony video-camera was positioned directly to the right of the ball placement in the sagittal plane and was used by the investigator to validate the subject's pre-assigned stage level. Filming began on an oral signal from the primary investigator before the subject began the approach run and ended on an oral signal after the subject completed the kick. The trials for all 20 subjects were recorded in this manner. The test area is illustrated in Figure 4.

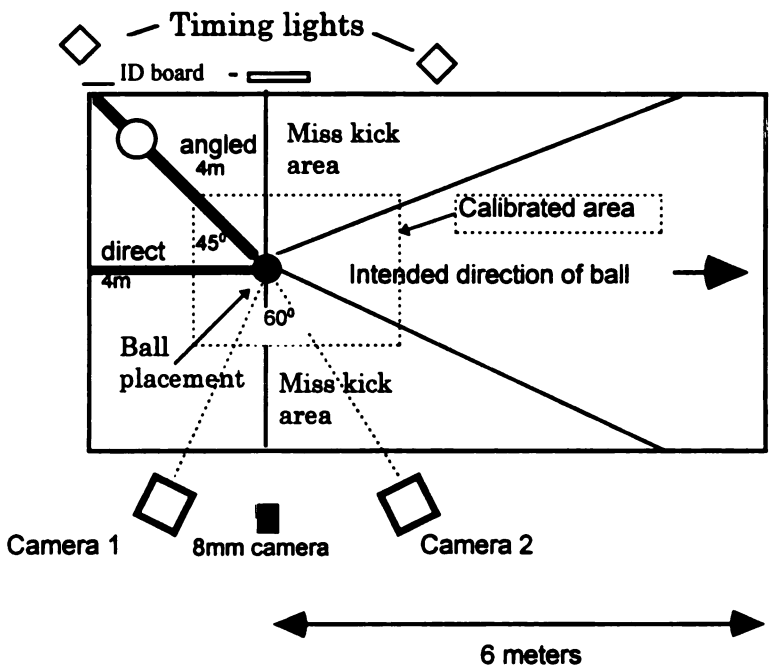

Figure 4. Test area setup.

Identification of subjects and trials

To identify the subjects and trials, a dry erase board was placed in view of each of the two cameras. The board contained a three digit number plus two letters. The first two digits represented the subject number (01 - 20), the second series of identifiers represented the trial number, the first letter represented the ball (A - Micro Soccer ball and B - standard size 3 ball), and the second letter represented the approach type (D - direct and A - angled).

Kicking procedures

Following a warm up period of five minutes of kicking with a rubber playground ball, all subjects completed three good trials with each ball type utilizing a direct approach to the ball. The five minute warm up was deemed appropriate because the kicking trials were within routine play for children, therefore risk of injury was minimal. The Stage Three and Four subjects also performed three good trials of the kick using an angled approach for each type of ball used in this study. A total of six good trials were recorded for the stage one and stage two subjects, whereas a total of 12 good trials were recorded for each subject in stages three and four. Three good trials per ball were selected in order to ensure that foot/ball contact was captured during filming. From those three good trials, one best trial was chosen for analysis based on foot ball contact.

The direct approach as used in the MSU developmental sequence of kicking, was one technique analyzed for this study. A 45 degree angled approach also was used by each subject classified as Stage Three or Four. To aid each subject's approach, two lines, one for each approach were taped on the floor using electrical tape. One taped line was parallel to the intended line of flight, while the second taped line was 45 degrees to the intended line of flight of the ball. The subjects were allowed a maximum of a four meter approach to the ball, and could start anywhere on the respective approach line. Limitation of the approach distance eliminated an excessive run to kick the ball. Each subject was randomly handed either the Micro-Soccer ball or standard ball as determined by a table of random numbers, with an even number being assigned to the Micro-Soccer ball and an odd number being assigned to the standard ball. While the subject was holding the test ball, the primary investigator demonstrated the specific type of kick for each subject. The subject was instructed to place the ball on a taped mark on the floor and back up as far as desired, but not past the end marker (orange cone). The subject was then instructed to kick the ball as hard as possible toward a stationary wall. Each subject was given as many extra trials as necessary to obtain three good trials. The "miss kick/out of bounds" area was taped on the floor to aid the researcher in the determination of a miss kick (Figure 4).

Following the trials, the subject and parents were taken by an assistant investigator to an adjoining room and asked a series of exit questions (Appendix C). These questions were used to assess the subject's perceptions of the two balls. As a result of each subject handling the two balls (treatment levels) and personally placing them on the floor to be kicked, the assumption was that the opportunity for gaining personal perceptions of the ball were standardized across the subjects. It should be noted that both balls were of similar color (yellow) and design pattern. The balls were of a similar color in order to eliminate any confounding influence color may have had in this study.

Data reduction

The Ariel Performance Analysis System (A.P.A.S.) was used to digitize the video data and to calculate angular displacements, velocities and accelerations. The calibration structure was digitized first in accordance with this system's procedures. Prior to digitization, the best trial for each approach and ball for each subject was selected by the primary investigator after viewing the three best recorded trials and selecting the trial with the best view of foot/ball contact. Within the grabbing module of A.P.A.S., every frame from five frames before support foot contact to five frames past the maximum follow through position was selected for analysis. The order of digitization remained the same for each subject (Figure 2), beginning at the fifth metatarsal and ending with the superior iliac crest. The A.P.A.S. transformation module was used to combine the two, two-dimensional digitized views of the two cameras. The result of this transformation of data was the three-dimensional points used in the analysis. Data were smoothed using the cubic spline method within the A.P.A.S. system. Angular displacements, velocities, and accelerations were calculated and analyzed for the segments defined by the points digitized. Hip joint angles were calculated between the pelvis and the thigh segments defined by the superior iliac crest and greater trochanter, and the greater trochanter and mid point of the knee markers, respectively. Flexion was defined as a decrease in angle, whereas extension was defined as an increase in angle. Knee joint angles were calculated between the thigh and the shank segments defined by the greater trochanter and mid point of the knee, and the mid point of the knee and lateral malleolus markers, respectively. A hip joint angle of approximately 90^0, and a knee joint angle of 180^0 indicates that the hip is in a flexed position, while the knee is straight, or fully extended. The specific joint angles were calculated between the adjacent segments as follows: Segment angles are measured from the horizontal of the last point digitized for that segment, counter clockwise, to the segment itself, as depicted in Figure 5(a). Then a second segment angular measure is calculated from that same horizontal line to the more proximal segment. Therefore, the hip angle was calculated by subtracting the thigh segment angle from 360^0, and then adding pelvic tilt angle.

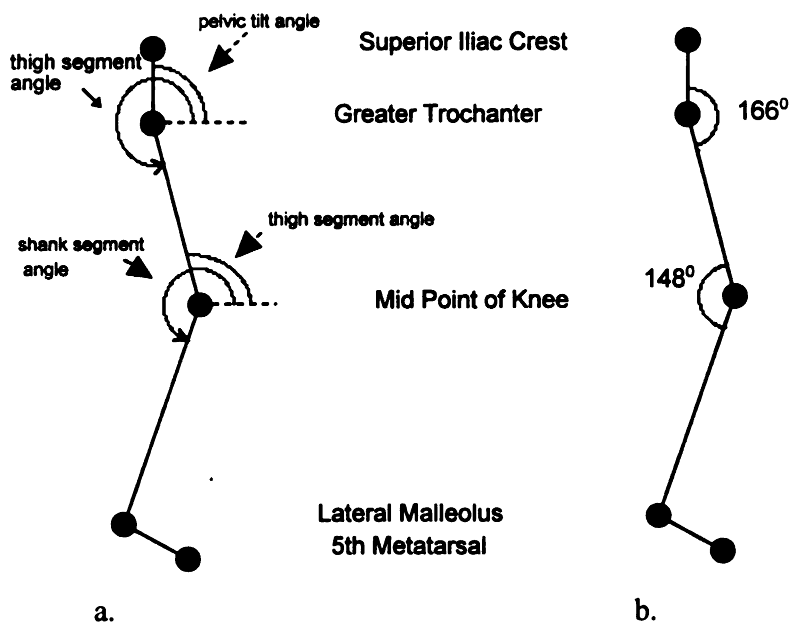

Figure 5. Segment and joint angles. (a) Method for segment angle calculations. (b) Joint angles used after segment angle calculations.

The knee joint angle was calculated by taking the shank segment angle and subtracting from it the thigh segment angle. Figure 5(b) illustrates hip flexion of 166^0 and knee flexion of 148^0.

Statistical analysis

The data collected were used to test the following hypotheses:

1. Each of the kinematic variables will follow the predicted trends as stated (see p. 7).

Kinematic variables:

The kinematic variables include the angular displacements, velocities, and accelerations of the thigh and shank segments at distinct positions during the kick. These positions were: a) maximum backswing of the kicking leg, b) foot/ball contact and c) maximum forward movement of the kicking foot after the ball leaves the foot.

These kinematic variables were expected to follow the predicted trends, for each stage for each approach, as defined for the preparatory phase, contact phase (force production phase), and the follow through phase.

2. There will be a difference in the rotations of the thigh, as well as the shank, of the kicking limb between subjects exhibiting stages three and four, while using a standard youth soccer ball and a direct approach to the ball. The stage four subjects will exhibit a more mature pattern of the kicking limb than the stage three subjects, as rotation of the thigh will be greater in the initial portion of the force production phase, with minimal rotation of the shank about the knee joint. In the later portion of force production phase, thigh rotation will decrease as shank rotation increases to ball contact.

3. There will be a difference in the rotations of the thigh, as well as the shank, of the kicking limb of the subjects using a direct approach, when compared with subjects using an angled approach, while kicking a standard youth soccer ball.

4. The resultant ball velocity of the light weight soccer ball will be greater than that of the standard youth soccer ball, regardless of approach.

Following data reduction, a computation of the descriptive statistics for the selected kinematic variables was performed with the Mini-Tab computer program. An ANOVA (Mini-Tab Software) was used to test each of the hypotheses with a significance level of $p < .10$ used in order to maximize the sensitivity of the test. Several biomechanical studies have questioned the use of a low significance value or have used a more generous significance level in the statistical treatment of data (Barfield, 1995; Kiger, 1987). The use of a $p<.10$ was determined to be acceptable as a result of the work by Kiger and Barfield. Additionally, further support for the use of a $p<.10$ is that, in human movement research, gross measurement methods, including videography, joint marker placement, and digitization, may obscure subtle human movements. The use of a $p<.05$ increases the risk of missing real differences as a result of the data collection and reduction processes. Furthermore, since qualitative characteristics distinguish points along a continuum of elementary to mature skill, and since biomechanical research techniques are more likely to distinguish extremes rather than gradations in performance (Ulibarri, personal communication, February 21, 1997), the use of a $p < .10$ is further supported in this study in order to identify differences in performance.

Chapter 4

RESULTS AND DISCUSSION

A biomechanical analysis was used in this study to investigate quantitative variables associated with the development of kicking in children three to eight years of age. Videographic methods were used to record the kicking trials of 20 children. Subsequent digitization of selected trials provided two, two-dimensional sets of data which using D.L.T. provided three-dimensional coordinates. Selected kinematic variables, at specific periods during a kick, were obtained for analysis from these sagittal plane three-dimensional coordinates.

Three purposes were identified for this study and were discussed in the following pages. The areas of investigation were: (a) to identify the selected kinematic variables of angular displacements, velocities, and accelerations associated with children exhibiting kicking stages one through four (Haubenstricker et al., 1981) during a direct approach, using both a standard size three soccer ball and a newly developed light weight soccer ball; (b) to identify the differences in the selected kinematic variables associated with children exhibiting kicking stages three and four using direct and angled approaches to the ball; and (c) to identify the effect ball weight had on the selected kinematic variables for stage levels three and four, by examining resultant ball velocity relative to the approach used.

Kinematic variables

The selected kinematic variables included the angular displacements, velocities, and accelerations for the thigh as well as the shank. Three specific points in a kick which coincided with the end of the preparatory phase, the contact period of the force production phase, and the end of the follow through phase of a kick were used as the periods in the skill from which the selected kinematic variables were calculated: (a) maximum back swing of the kicking leg (MBS); (b) foot and ball contact (FBC); and (c) maximum height (MFM) of the kicking foot in the follow through .

Developmental trends for the gross motor skill of kicking using a direct approach to the ball have been identified by several researchers (Seefeldt and Haubenstricker, 1972; Haubenstricker et al., 1981). The current study quantified predicated characteristics of selected kinematic variables for stages one through four, using a direct approach, when kicking a standard youth soccer ball. Additionally, this study incorporated a newly developed lightweight ball to determine if ball weight had an effect on the identified selected kinematic variables. Furthermore, predicted characteristics of selected kinematic variables were developed for an angled approach by Basic Stage and Mature Stage kicking skills. These predicted characteristics were identified for both the standard size three ball and the Micro-Soccer ball.

Developmental trends for the direct approach

The developmental sequences of kicking by Seefeldt and Haubenstricker (1972) provided a foundation from which to quantitatively assess the sequences of changes associated with the development of kicking in children. (For a detailed review of the sequences, see pages 20 - 22 of Chapter 1.) The results of children exhibiting stages one through four using a direct approach to kick a standard youth soccer ball (size three) and a lightweight soccer ball, were presented within this section. The current study examined the effect of ball weight on selected kinematic variables of kicking in children by use of the Micro-Soccer ball, a newly developed light weight soccer ball.

Preparatory phase

The preparatory phase of any gross motor skill is important in executing the skill with the utmost success, as this phase establishes the foundation for the specific technique a subject will use in developing force, by placing the body in a position for force production. It was predicted that the stage one performers would not exhibit hyperextension of the hip joint, while the stages two through four performers would have increasing amounts of hip joint hyperextension. This predicted trend was developed on the premise that, as skill level increased, the approach stride length of the stage three and four performers would increase, resulting in hip hyperextension of the kicking leg . A greater stride toward the ball is important as it increases the distance through which the leg can swing, allowing the leg to reach higher velocities, prior to contact, than if a shorter stride were used.

The joint angles of the hip for all stages did not meet the predicted angles expected during the preparatory phase. Using the standard soccer ball the stage one performers exhibited a neutral position at 180^0. Stages two, three and four performers' hip angles were 171^0, 177^0 and 174^0 respectively. Therefore, subjects in stages two through four did not exhibit increasing hip hyperextension during maximum backswing as was predicted (Table 4). Likewise, the subjects using the lightweight Micro-Soccer Ball did not exhibit increasing hip hyperextension (Table 4). In comparison with the results of the standard ball the stage one subject's hip was more flexed using the Micro-Soccer Ball (Figure 6, Note: for ease of drawing, figures are oriented to the vertical).

Table 4

Mean Hip and Knee Joint Angles (degrees) at Maximum Backswing for Stages 1 - 4

Stage	1	2	3	4
Hip (MBS)				
Standard Ball	180	171	177	174
Micro-Soccer Ball	162	174	175	168
Knee(MBS)				
Standard Ball	160	161	135	142
Micro-Soccer Ball	157	172	128	139

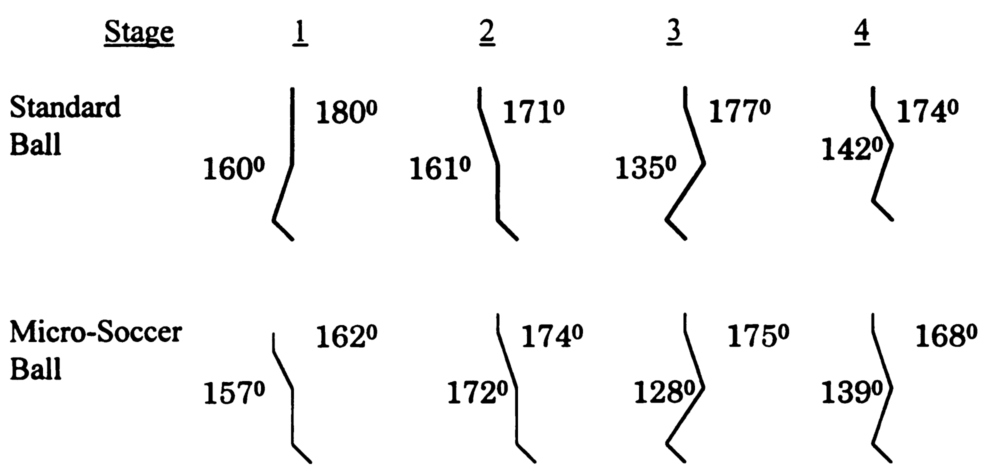

Figure 6. Mean hip and knee joint angles at maximum backswing, stages 1 - 4.

Perhaps a misperception of the trunk position relative to the thigh, may explain the absence of the hyperextended hip position as described by Haubenstricker et al. (1981). As the performer becomes airborne, and if the trunk is inclined anteriorly, at maximum backswing of the kicking leg, hip hyperextension may appear to be present. However, if the position of the trunk is examined relative to the thigh, this hyperextension may not exist. This misperception may result in inaccurate assessments of hip positions relative to the trunk. Additionally, hyperextension of the lumbar vertebrae could result in a similar misperception of hyperextension at the hip. Lumbar hyperextension would cause an anterior rotation of the pelvis and, relative to the thigh, may appear to be hip hyperextension.

It was expected that knee flexion at maximum backswing would increase sequentially from stage one to stage four. Using the standard soccer ball, the values for the knee joint were similar for stage one at 160^0, and stage two at 161^0. Extension was found between stage one (157^0) and stage two (172^0) with the Micro-Soccer Ball. The stage three performers had greater knee flexion than the stage two subjects 135^0 and 128^0, respectively, for the standard ball and Micro-Soccer ball. The difference between stages two and three can be attributed to the use of a deliberate approach of the stage three subjects. The use of a deliberate approach would enable the stage three performers to take advantage of increased momentum, both of the body and kicking thigh, which would result in greater knee flexion. However, an increase in extension was observed from stage three to the stage four subjects, 142^0 and 139^0 for the standard and Micro-Soccer ball respectively. The stage four subjects' more extended knee, in comparison to the stage three subjects, may have been due to being airborne. The stage four subjects most likely capitalized on the increased momentum of the body and may not have required as much knee flexion in comparison to stage three (Table 4).

The similarity of stages one and two (standard ball) can be explained by the stationary approach used by the subjects, which resulted in similar backswings. The difference seen in the stage three and four subjects could have been as a result of greater coordination during the backswing for the stage four subjects. Knee flexion which was expected to increase sequentially across the stages, was not found (Table 4), with only stage three performers exhibiting an increase in knee flexion from stage two. Stage three performers used a deliberate but not airborne approach to the ball. As a result of not being airborne, the stage three subjects may have required greater knee flexion in the preparatory phase in anticipation of generating force during the force production phase of the skill.

When the hip joint was examined in conjunction with the knee joint during backswing, the stage one subjects moved the thigh and shank of the kicking leg as a single unit when using the Micro-Soccer Ball (Figure 7). The large difference from stage two to stage three using both ball types was likely as a result of a moving approach for the stage three subjects. As a result of the increased momentum of the body or thigh, or a combination of both for stage three performers, knee flexion occurred, as the hip joint remained relatively extended during the final step. The relationships of knee and hip angles at maximum backswing between the stages for the direct approach kicking both ball types, illustrated in Figure 7, could be explained by the stage four subjects' leap, on the last step of the approach. All of the stage four subjects exhibited a leap, in contrast to the stage three subjects who all used a step with their approach. An increase in coordination and timing between the thigh and the shank for the stage four subjects would be expected when compared to the stage three subjects.

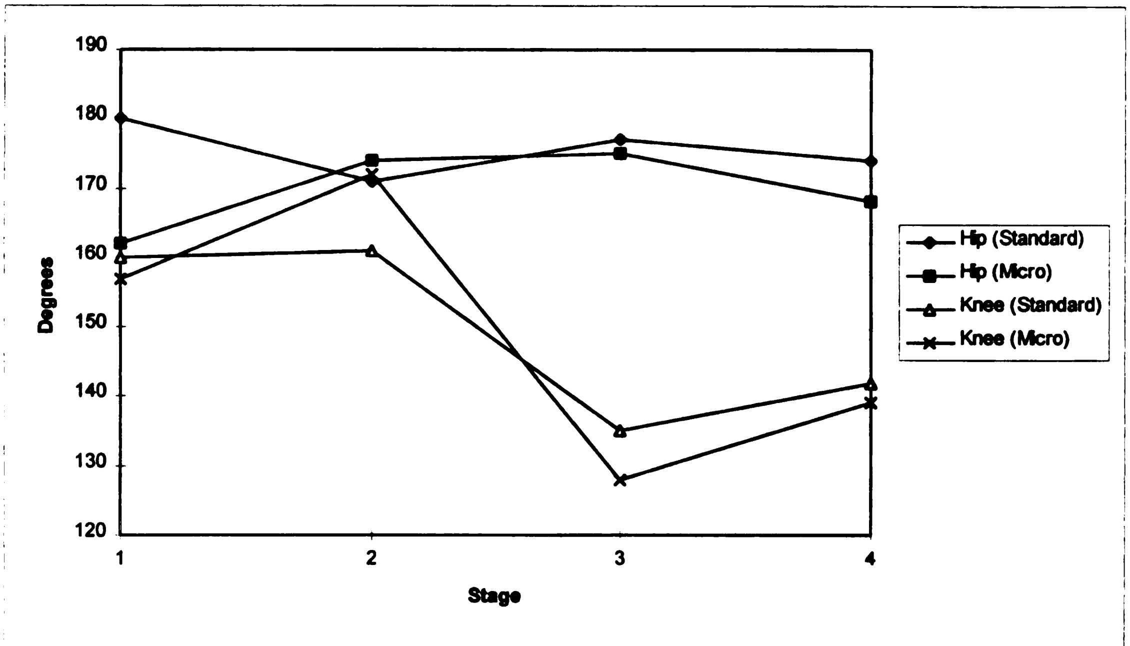

Figure 7. Knee and hip angles at maximum backswing for stages 1-4.

The stage three subjects may have to rely more on the stretch reflex of the muscles involved in the kick than the stage four subjects, and would have positioned the segments in order for the muscles to invoke the stretch reflex. The stage four performers, it would seem, would have both the body's momentum and the stretch reflex, whereas the stage three performers would have only a step and the stretch reflex. Additionally, the stage four performers, because of the increased momentum, do not need as great of a contribution from the stretch reflex, although the reflex is probably invoked due to reversal of the thigh forward relative to the shank, in the backswing. The stretch reflex has been described as a self regulatory mechanism, enabling the muscles to automatically adjust as a result of increased load or length, in order to support the desired movement pattern, resulting in a stronger contraction than if the reflex had not been involved (McArdle, Katch & Katch, 1996).

Contact phase

The force production phase of a kick is critical in assessing performance, as this is where the culmination of the subject's technique is expressed. The orchestration of the movement pattern is exhibited in the velocity of the kicked ball. Maximum ball velocity (Luhtenan, 1988) or angle of ball projection (Too and Hoshizaki, 1984) was used by researchers to assess kicking performance. The study by Luhtenan (1988) helped in validating the results of the current study. Luhtenan determined resultant ball velocity to be 14.9 m/sec for the 9-12 year old subjects in his study. For the most skilled kickers in the current study, ball velocities for the direct approach were 11.66 and 14.24 m/sec for a standard youth soccer ball and a lightweight soccer ball, respectively. At the time of this writing no studies had investigated angular displacements, velocities and acceleration for children while kicking. Motor skill development is age related but not age dependent. Therefore, the comparison of segment rotations between adults and children would be a study of its own. This researcher predicted that the angular displacements, velocities, and accelerations of the kicking leg segments would increase from stage one through stage four. Additionally, it was predicted that the knee joint of the kicking leg would have a greater amount of extension at ball contact for stage four performers than stages one through three, and that the stage four performers would reach full knee extension (180^0) at ball contact.

The stage one performers positioned the thigh at a mean hip angle of 155^0 with the standard ball and 150^0 with the Micro-Soccer Ball. This flexed position was different than the expected position of 90^0 of hip flexion as was predicted and as was described by Haubenstricker et al. (1981). Slightly different hip joint angles for all four stages were found, with an overall mean range of 150^0 to 162^0 at contact, for the standard youth soccer ball and 145^0 to 154^0 for the Micro-Soccer Ball (Table 5, Figure 8).

Table 5

Mean Hip and Knee Joint Angles (degrees) at Contact for Stages 1-4

Stage	1	2	3	4
Hip(FBC)				
Standard Ball	155	162	154	150
Micro-Soccer Ball	150	154	152	145
Knee(FBC)				
Standard Ball	127	112	89	89
Micro-Soccer Ball	131	108	95	95

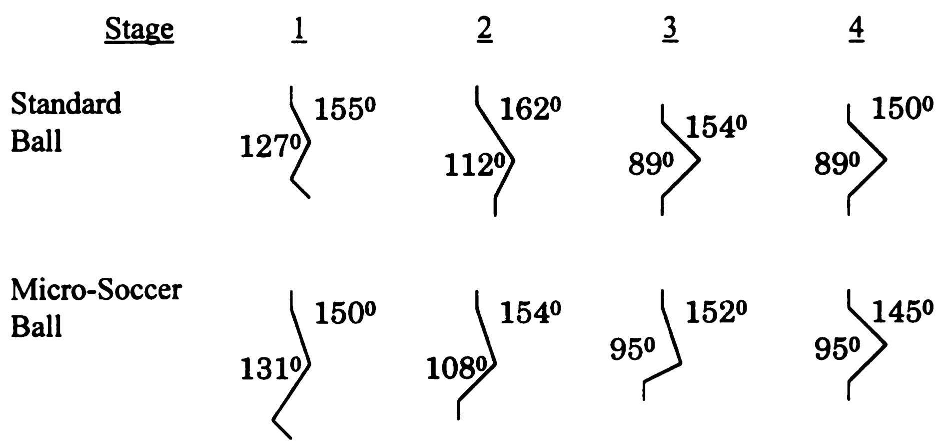

Figure 8. Mean hip and knee joint angles at contact, stages 1 - 4.

The exact position of the knee at ball contact has been described by Plagenhouf (1971), and was predicted to be at full extension at ball contact for the stage four performers. The performers were predicted to have sequentially increasing degrees of knee extension from stages one to four, respectively. Instead, flexion at the knee joint was found to increase sequentially across stages at contact for both soccer balls. Only minimal differences in knee flexion angles were found between ball types. The range of knee joint position for the stages with the standard ball was from 127^0 for the stage one subjects, to 89^0 for the stage four subjects. The ranges of knee joint position were similar with the Micro-Soccer Ball (Table 5, Figure 8). Full knee extension was not reached at contact for any performer at any stage with either ball.

The relationship between the hip and knee angles at contact were illustrated in Figure 9. Stage levels are located along the X axis, with degrees along the Y axis. As stage level increased from stage two to stage three the knee angle decreased and the hip angle decreased, while maintaining a flexed position. The increase in the hip angle from stage one to stage two was due to the increased momentum generated by the stage two subjects versus stage one. The decrease in hip angles from stages three to stage four reflected the segmental relationship discussed by Putnam (1991).

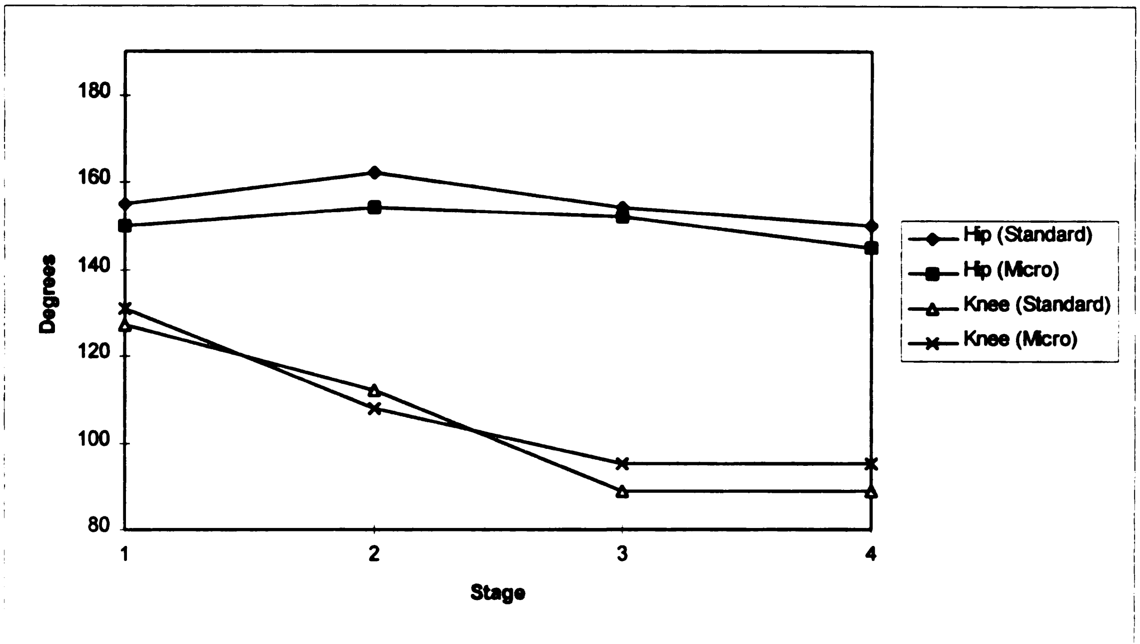

Figure 9. Relationship at contact between the knee and hip joints during the direct approach for stages 1-4.

According to Plagenhoef (1971), in order to reach maximum force production during a kick, the knee must be fully extended to take advantage of the summation of forces involved with the skill of kicking. As was discussed earlier, Putnam (1991) did not fully agree with this theory as applied to kicking. Putnam's disagreement dealt with the lack of explanation of the relative contributions of the segments. Putnam further discussed that if one looked only at the distal segment's maximum speed (summation of forces), one would sense that at the moment of impact all the joints involved during a kick would be fully extended and the angular rotations of the segments would be equal to each other. Investigations by several researchers (Barfield, 1993; Putnam, 1983; Luthanen, 1988; Isokawa and Lees, 1988; Glassow and Mortimer, 1968) of angular rotations of the leg segments during a kick have shown these rotations not to be equal at impact. Putnam (1993) also stated that the proximal to distal sequence observed in the pattern of kicking could not be explained by a concomitant sequence of muscle forces. Putnam stated that there is no evidence that the forward swinging motion of the shank in kicking, running, or walking was initiated by the larger muscles of the proximal segment and continued by the smaller muscles of the distal segment, as suggested in the summation of forces principle. Putnam's theory helped to explain the contribution of the segment motions related to the outcome of a kick.

The results of the current study indicated that different patterns of movement were evident in the sample of children than predicted. The finding of a sequential increase in knee flexion from stages one to four was in direct opposition to the work by Haubenstricker et al. (1981). Additionally, the National Soccer Coaches Association of America (NSCAA) academies for coaches teach a flexed knee at contact for skilled soccer players. A flexed knee is achieved by instructing the athlete to position the knee over the ball at contact. Because the foot is fixed in plantar flexion at contact, knee flexion is required in order to prevent the foot from striking the ground prior to ball contact. Also, the figures in the text by Gallahue and Ozman (1998) show knee flexion at contact for a mature level performer.

It was hypothesized that angular displacements, velocities and accelerations of the segments of the kicking leg would increase with each stage level. Contrary to the tested hypotheses, not all variables were found to increase progressively across stages using the standard soccer ball nor the Micro-Soccer ball (Table 6).

Table 6

Kinematic Variables for Subjects' Stages 1-4 at Contact

	Stage	1	2	3	4
Angular (standard ball)					
Mean Displacement (deg)					
Shank		237	214	205	213
Thigh		282	281	295	301
Mean Velocity (deg/sec)					
Shank		-80	30	572	1012
Thigh		292	446	603	538
Mean Acceleration (deg/sec^2)					
Shank		3606	6239	12012	8355
Thigh		1417	864	-1639	-6698
Angular (Micro-Soccer ball)					
Mean Displacement (deg)					
Shank		238	221	217	221
Thigh		288	293	301	306
Mean Velocity (deg/sec)					
Shank		24	306	690	1146
Thigh		287	468	428	522
Mean Acceleration (deg/sec^2)					
Shank		3642	7358	7596	7900
Thigh		3	36	-3958	-8044

Shank angular displacements decreased from stage one (at 237^0) sequentially to stage three (205^0) and then increased from stage three to stage four (213^0) with the standard ball. A similar decrease in the shank angular displacement was also found for the Micro-Soccer ball (Table 6). The change seen from stage one to stage three could have been as a result of the deliberate, moving approach of the stage three subjects. The moving approach would have resulted in greater knee flexion for the stage three subjects, compared to subjects in stages one and two, as a result of the increased momentum generated by the shank segment of the stage three subjects. The increase in shank angular displacement was likely due to the initial forward movement of the shank (extension of the knee). Although mean thigh angular displacement decreased slightly from stage one (282^0) to stage two (281^0), upon closer examination showed that the displacement between these two stages was maintained with use of the standard ball. An increase in mean thigh angular displacement was seen between stage two (281^0) to stage three (295^0) and again increased slightly between stages three and stage four (301^0). A slight increase in thigh angular displacement across the four stages was illustrated with Micro-Soccer ball use. The progressive increase in angular thigh segment displacement indicated that, across the stages, hip flexion occurred during kicks, for both soccer balls. Hip flexion would be expected to increase across the stages due to a more coordinated timing of the kicking sequence, as the stages progressed from stage one to stage four.

Mean shank angular velocity increased across the four stages from -80 deg/sec (stage one) to 30 deg/sec (stage two), increased dramatically to 572 deg/sec for stage three and increased again to 1012 deg/sec for stage four with the standard ball. Kicking the Micro-Soccer ball (380 deg/sec) did not result in as great of a difference in mean shank angular velocity between stages two and three as with the standard ball (500 deg/sec). An approximate 500 deg/sec increase occurred in mean shank angular velocity between stages three and four, using both balls. As discussed earlier, the stage one subjects moved the leg segments as one unit which limited velocity, whereas the stage two subjects moved the thigh and shank independently. The stage two performers would be able to achieve increased velocity over stage one performers as a result of the independent movement of the shank relative to the thigh. The increase from stage two to three can be attributed to the moving approach by the stage three subjects causing greater velocities to be achieved. The increase between the stage three and four subjects can be explained by the airborne phase on the last step by the stage four subjects. This leap increased the velocity of the body, and since momentum is the product of mass and its velocity, the stage four subjects were able to capitalize on the forward movement of the body, resulting in increased segment velocities over stage three performers.

Mean thigh angular velocity with the standard ball increased from stage one (292deg/sec) to stage two (446 deg/sec) and increased again between stage two and stage three (603 deg/sec). A decrease in mean thigh angular velocity of 65 deg/sec was found between stage three (603 deg/sec) and stage four (538 deg/sec) with the standard ball. Similarly with the Micro-Soccer ball, mean thigh angular velocity increased from stage one to stage two (Table 6). However, it decreased from stage two to stage three. An increase in mean thigh angular velocity was found between stages three and four with the Micro-Soccer ball. The difference in thigh angular velocity between stages three and four could be attributed to the soccer paradox found in the stage four subjects.

The mean shank angular accelerations with the standard ball increased by 2633 deg/sec^2 from stage one (3606 deg/sec^2) to stage two (6239 deg/sec^2) and increased by 5773 deg/sec^2 between stage two (6239 deg/sec^2) and stage three (12012 deg/sec^2). The mean shank angular acceleration with the standard ball decreased 3657 deg/sec^2 between stage three (12012 deg/sec^2) to stage four (8355 deg/sec^2). The rate of change in angular velocity of the shank for the stage four subjects was not as great as for the stage three subjects which resulted in a deceleration of the shank for the stage four performers while using the standard ball. This deceleration illustrated differences in timing and coordination between the stages. Using the Micro-Soccer ball a progressive increase in angular acceleration of the shank was found from stage one (3642 deg/sec^2) to stage four (7900 deg/sec^2). The progressive increase from stage one to stage two illustrated the increased capability of the stage two subjects to produce increased segmental rotations as a result of moving the thigh and shank independently to contact.

The mean thigh angular acceleration with the standard ball progressively decelerated from stage one (1417 deg/sec^2) to stage two (864 deg/sec^2), from stage two to stage three (-1639 deg/sec^2), and from stage three to stage four (-6698 deg/sec^2). In contrast, using the Micro-Soccer ball, mean thigh angular acceleration minimally increased from stage one to stage two (33 deg/sec^2, Table 6). A progressive deceleration occurred from stage two to stage three as in the results with the standard ball results. The progressive sequential deceleration of the thigh was explained as a result of the increasing skill level from stage one to stage four. As found in the literature, as skill level increased, the thigh decelerates to the point of possibly reversing direction at contact. The decreased shank accelerations of the stage four performers could be attributed to a more coordinated movement pattern, which includes the soccer paradox. The stage four subjects likely relied on and were able to capitalize on the contributions of the deceleration of the thigh.

The prediction for both ball types that the stage four performers would exhibit a decrease in thigh angular velocity, as the shank angular velocity increased to ball contact, was supported by these data. The stage four performers' mean angular velocity of the shank was greater than that of the thigh angular velocity (Table 6). Not surprisingly, this segmental relationship was further supported by the accelerations of the thigh and shank. The shank continued to accelerate at ball contact, but the thigh decelerated for the stage four subjects (Table 6). In comparison, the stage three subjects' mean shank and thigh angular velocity was lower than the stage four subjects at contact with the Micro-Soccer ball. Although not predicted, the stage three subjects' shank continued to accelerate at contact, while the thigh decelerated. One might conclude from this comparison that the soccer paradox existed for the stage three subjects with both ball types. However, the differences in magnitude between the rotations of the shank and the thigh of the stage four subjects were much greater and characterized the more mature pattern of this fourth stage. Additionally, the deceleration of the thigh was much greater for the stage four subjects, which was consistent with the literature on skilled performers. These segmental relationships were found in the stage three and four performers' results for both ball types used: the standard soccer ball and the Micro-Soccer ball.

Follow through phase

Knee extension was predicted to continue after ball contact during the follow through phase of the kick and was supported by the data analyzed. Although the absolute knee angles were not seen to increase sequentially across stages, the relative change in the knee joint angles, in fact, did increase with stage for both ball types, with the exception of the stage three performers using the Micro-Soccer Ball (see Table 7, Δ Deg). The standard ball knee angles are listed first followed in parentheses by the angles for the Micro-Soccer ball in Table 7. The column, Δ Degree, was found by taking the knee joint angles at contact and subtracting them from their respective stage knee joint angles at maximum forward movement. Figure 10 is provided to aid the reader's understanding of the positions of the segment's relationships to each other (Figures are oriented to vertical).

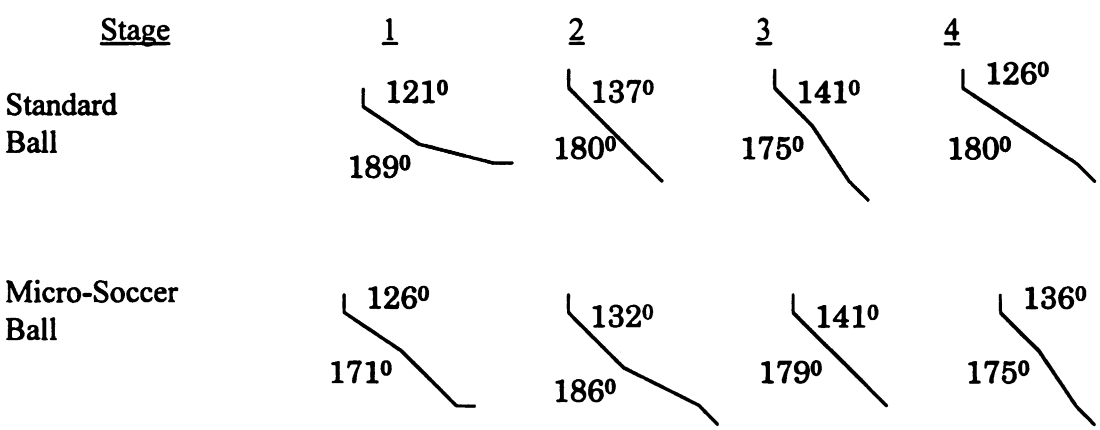

Figure 10. Mean hip and knee joint angles at maximum forward movement, stages 1 - 4.

The knee joint angle extended from contact to maximum forward movement of the kicking foot across all stages with both ball types. Slight hyperextension of the knee was seen in the stage one and two performers at maximum forward movement with the standard ball. Only stage two exhibited slight knee hyperextension with the Micro-Soccer Ball.

Table 7

Knee Joint Angles (degrees) from Contact to Maximum Forward Movement for Stages 1-4 with a Standard Ball (Micro-Soccer Ball)

Stage	FBC	MFM	Δ Deg
1	127 (131)	189 (171)	62 (39)
2	112 (108)	181(186)	69 (78)
3	89 (95)	175 (179)	85 (84)
4	89 (95)	180 (175)	91 (79)

Although no hypotheses were formulated pertaining to the relative change in knee joint angle from contact to maximum forward movement, the change in knee joint angle may be a more appropriate method for illustrating differences between stages than solely examining a single point during the follow through. Examining the relative changes provides information related to the changes taking place during the sequence. Although the analysis in this study considered only the leg segments, it is likely that other body segments may play a role during the follow through. For example, the opposition of the arms relative to the legs would be expected to aid in the timing of the kick and balance of the body. Also the decrease in relative knee joint angles of the kicking leg may be related to balance, specifically while in the air. Given that the stage four subjects were airborne, the decrease in the relative difference of the knee joint angle from stage three may have been a result of an in flight spatial adjustment. The decrease in the moment arm of the leg about the hip would aid in the performer's balance.

The final predicted characteristic during the follow through phase was that the stage four subjects would be airborne following contact. All of the stage four performers were airborne in the follow through phase, further supporting the identification of those subjects as stage four. Only two of the stage three performers appeared to be aggressive enough in the kick to exhibit plantar flexion on the support foot during the follow through phase, but the momentum produced by the kick was not great enough to cause the subjects to become airborne. Because of other criteria for stage four classification, had the stage three performers become airborne, they would have not been classified as a stage four performer.

Few of the predicted characteristics were found for the direct approach with a standard youth soccer ball and the lightweight Micro-Soccer Ball. The predicted characteristics that were found occurred at contact. At contact, angular acceleration of the thigh decreased and knee flexion increased sequentially across all stages. The mean shank angular velocity was found to increase across the stages, accompanied by a progressive increase in the angular acceleration of the shank. Additionally, because a simultaneous decrease in thigh velocity was accompanied by an increase in shank velocity for the stage three performers these subjects may have exhibited the beginnings of the segmental relationship of the soccer paradox. Finally at contact, the stage four subjects exhibited the segmental relationship of a decrease in thigh velocity as the shank increased in velocity. The stage four subjects exhibited a greater difference between the rotation of the thigh and shank when compared to the stage three subjects, indicating a higher skill level for stage four. During the follow through, all of the stage four subjects were found to be airborne. Based on these results it appeared that a lightweight ball (Micro-Soccer Ball) did not have an effect on the specific patterns of movement of the children selected for the current study.

Developmental trends for the angled approach

Developmental sequences for the gross motor skill of kicking have been published in the literature and were discussed earlier. To date no literature has been found on the developmental sequences of an angled approach to a ball, as is seen in soccer players. Subjects who matched criteria for stages three and four (Haubenstricker et al., 1981) were further examined using an angled approach. As previously stated, the reason for the use of only stages three and four, was that stages one and two do not use a deliberate approach to the ball; rather they stand directly behind the ball and strike the ball without an approach. For the angled approach, the stage three performers were identified as Basic Stage performers, while the stage four performers were considered Mature Stage performers. Distinguishing characteristics of the Basic and Mature Stages were established in this study, and the results of the collected data were presented in this section. A detailed description of the predicted angled approach characteristics were outlined in Chapter One, pages 10 and 11.

Preparatory phase

During the preparatory phase of the angled approach, the performer followed a line off-set 45^0 relative to the direct approach of the ball. On the final step, it was determined that the support foot of the non-kicking leg was positioned along the angled approach path for all Basic Stage subjects for either ball. This foot positioning, resulted in several instances where the ball struck the matted wall well to the right of the center of the mat.

In contrast, all mature Stage performers placed the non-kicking support foot along the intended path the ball was to be kicked, rather than along the approach path, for both soccer ball types. A skill level pattern higher than a Basic Stage level appeared to be required to execute correctly an angled approach to the ball in order to direct the ball in the intended direction. Although accuracy was not a variable in this study, the above comment was an observation about the foot placement of the non-kicking support leg relative to the resulting direction of ball travel. The positioning of the support foot for both stages reinforced the postulated view that a higher skilled kicker will place the support foot along the intended line of flight of the ball. This foot positioning enables the higher skill level participant to involve more muscles over a greater range as a result of the body's position about the foot placement. Since the support foot leg is outwardly rotated, the muscles that are involve in inward rotation and adduction are utilized, increasing the amount of force applied to the kicking system. Additionally, the pelvis moves through a greater range of motion, which in turn carries the foot of the kicking leg through a greater range of motion and, in theory, aids in force production. Not only are more muscles involved, but the skilled performer is also more capable of directing the ball in the intended direction as a result of the support foot placement.

During the preparatory phase, hip hyperextension for the Basic Stage performers was predicted to occur, but in fact was not supported by the findings. The Basic Stage performers exhibited slightly more hip flexion with the standard ball than with the Micro-Soccer ball (Table 8, Figure 11). The Mature Stage performers were expected to exhibit

Table 8

Mean Hip and Knee Joint Angles (Degrees) at Maximum Backswing for the Basic and Mature Stages

	Basic	Mature	
Hip (MBS)	175	169	Standard Ball
	172	171	Micro-Soccer Ball
Knee (MBS)	135	144	Standard Ball
	130	141	Micro-Soccer Ball

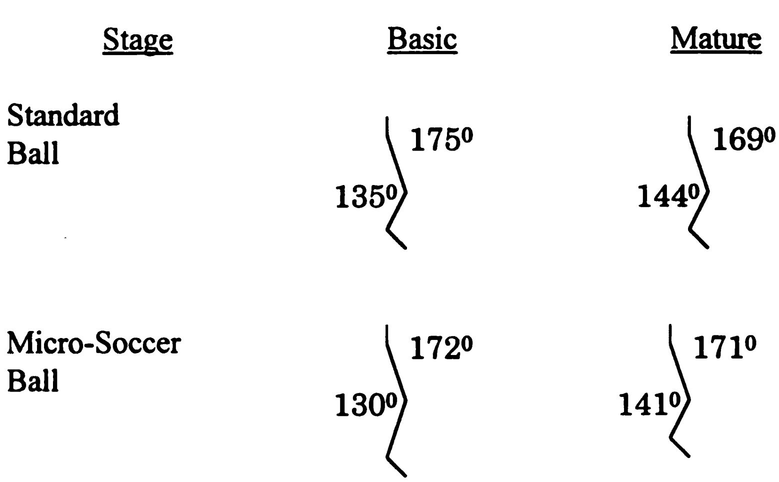

Figure 11. Mean hip and knee joint angles at maximum backswing for Basic and Mature Stages.

greater hip hyperextension than the Basic Stage performers. Instead, the Mature Stage performers' mean hip position was flexed more at maximum backswing than the mean hip position of the Basic Stage performers (Table 8, Figure 11). Although the magnitude of knee flexion was not specified for the Basic and Mature Stages, the mean positions of the knee for the Basic Stage performers for both ball types was flexed more than that of the Mature Stage performers as illustrated in Figure 12.

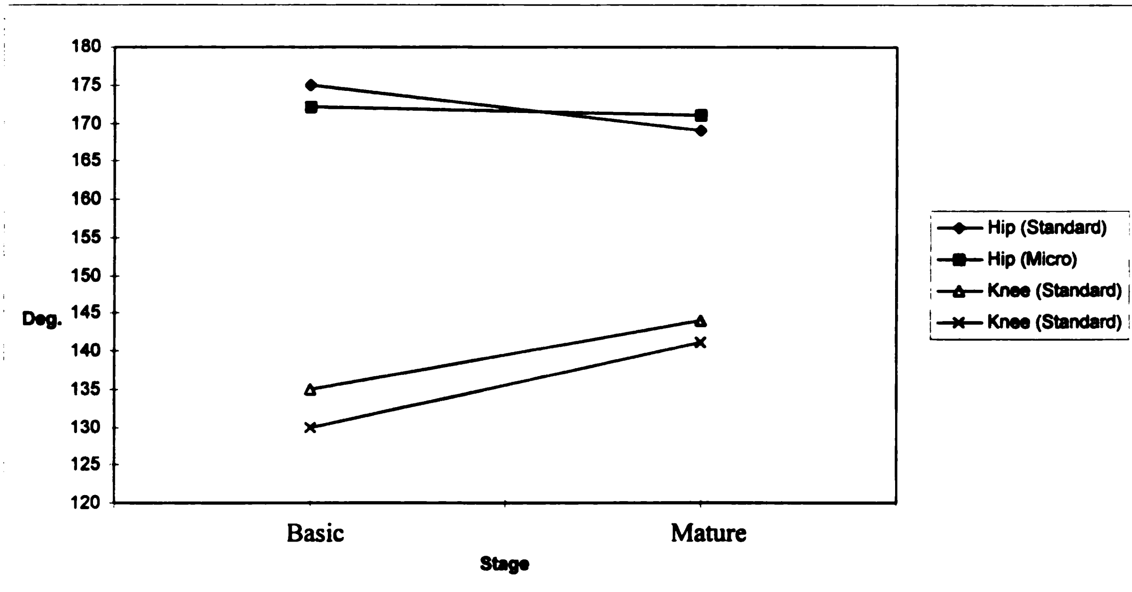

Figure 12. Hip and knee joint angles at maximum backswing for Basic and Mature Stages.

In the preparatory phase for both ball types, neither stage group exhibited hip hyperextension, and both stages exhibited knee flexion. It appeared that there was an inverse relationship between hip and knee joint angles and stage during the preparatory phase. That is, the Basic Stage subjects had greater hip extension and greater knee flexion than did the Mature Stage subjects. A possible explanation of the difference between the Basic and Mature Stages was in the relative length of the moment arm of the combined segments (thigh and shank). For example, together, the Mature Stage subjects' knee and hip joint flexion angles could have resulted in a shorter length of the moment arm relative to the hip than the Basic Stage subjects' moment arm length. Given the same amount of strength and power, the shorter moment arm would have enabled the Mature Stage subjects to swing the kicking leg faster initially, than the Basic Stage subjects. The generation of segmental velocities related to a shortened moment arm was outside the scope of this study. As stated previously, it is possible that the subjects did not exert a maximum effort during their approach; therefore, the leap during the last approach step potentially may not have been as dynamic, which could have resulted in a slightly flexed hip. Additionally, trunk flexion or anterior pelvic tilt caused by lumbar hyperextension also could have occurred which would result in the hip appearing to be hyperextended. It was beyond the scope of this study to evaluate trunk flexion or pelvic involvement during a kick, but relative positioning of these body parts could affect the perception of the thigh position relative to the trunk.

Contact phase

Another of the predicted characteristics established for Basic Stage performers during the force production phase, was that knee extension would occur as hip flexion occurred. This relationship of knee extension during hip flexion was not found with either ball. Instead, as hip flexion occurred, knee flexion occurred for both the Mature and Basic Stage performers as illustrated in Table 9 and Figure 13. The relative differences between maximum backswing and contact for the Basic and Mature Stage performers were also determined (Δ Deg, Table 9). The Mature Stage performers exhibited slightly less hip flexion from maximum backswing to contact and a greater difference in knee flexion from maximum backswing to contact than did the Basic Stage performers (Table 9 and Figure 13).

Table 9

Basic and Mature Stage Knee and Hip Joint Angles (degrees) at Contact with a Standard Youth Soccer Ball (Micro-Soccer Ball)

	MBS	FBC	Δ Deg
Hip Joint (Deg)			
Stage			
Basic	175 (172)	153 (150)	-22 (-22)
Mature	169 (171)	150 (152)	-19 (-20)
Knee Joint (Deg)			
Stage			
Basic	135 (130)	100 (94)	-34 (-35)
Mature	144 (141)	97 (100)	-47 (-41)

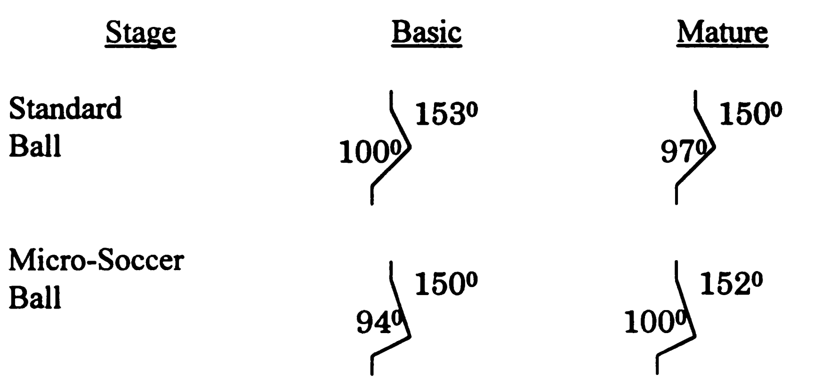

Figure 13. Mean hip and knee joint angles at contact for Basic and Mature Stages.

The principle of summation of forces was not supported by the findings of this study, as flexion at the hip joint with subsequent flexion at the knee joint was found. For the summation of forces principle to be followed, hip flexion followed by knee extension would be required. What was found was, the segmental relationship of the forward movement of the thigh (flexion at the hip joint), caused the shank to rotate posteriorly (flexion at the knee joint). These findings further supported the work by Glassow and Mortimer (1968) and Putnam (1983 and 1993). The resulting knee flexion may be exhibited in order for the performer to take advantage of the stretch reflex of the muscles involved in the movement.

The predictions that a Basic Stage performer would exhibit increasing thigh and shank velocities until ball contact were supported by these data. Illustrated in Table 10 were the mean angular velocities of the shank, and thigh of the Basic Stage subjects for both ball types used. For the standard ball, the shank angular velocity increased by 1019 deg/sec from maximum backswing to contact, while a smaller increase of 82 deg/sec was found for the Micro-Soccer ball. Additionally, the thigh exhibited a similar relationship as the shank, as it increased in velocity from maximum back swing to contact by 621 deg/sec, while an increase in velocity of 554 deg/sec was found for the Micro-Soccer ball (Table 10).

Table 10

Segment Velocity for Basic Stage Performers with a Standard Youth Soccer Ball (Micro-Soccer Ball)

Angular Velocity (deg/sec)	MBS	FBC	Δ
Shank	-348 (-240)	671 (582)	1019 (822)
Thigh	-48 (0)	572 (554)	621 (553)

For the Mature Stage performers using the standard ball, thigh angular velocity did not decrease from maximum backswing to ball contact. Instead, the increase in shank angular velocity to contact was greater than that of the thigh (Table 11). The same subjects using the Micro-Soccer ball exhibited a similar shank-thigh relationship as with the standard ball, but the magnitude of increase was greater (Table 11). This greater magnitude in angular velocity was believed to be as a result of the lighter weight Micro-Soccer ball. Further inspection of the results with both ball types confirmed the movement of the shank relative to the thigh; as the shank for the Mature Stage performer exhibited an acceleration, the thigh decelerated (Table 11). The deceleration of the thigh, relative to the shank has been described as the soccer paradox. Although not predicted, the Basic Stage subjects did exhibit a segmental relationship where the thigh decelerated as the shank accelerated (Table 11). It was the opinion of this researcher that the Basic Stage performers' segmental relationship was an elementary form of the soccer paradox.

The Mature Stage subjects had greater differences in magnitudes between the thigh and shank accelerations, than did the Basic Stage subjects. It is this greater difference in magnitudes between the shank and thigh acceleration that highlighted the Mature Stage performers' skill level when compared to that of the Basic Stage performers. The Mature Stage performers were more capable of utilizing the segmental relationships as compared to the Basic Stage performers to produce greater velocities and accelerations because of better timing and coordination.

Also indicated in Table 11, was that the shank velocity of the Mature Stage subjects at contact was greater for the Micro-Soccer ball than for the standard ball. Additionally, the acceleration of the shank and deceleration of the thigh was greater for the Micro-Soccer ball. The Basic Stage performers did not exhibit as great a difference in magnitudes between the ball types as the Mature Stage performers did.

Table 11

Velocity and Acceleration for Basic and Mature Stage Subjects at Contact Using a Standard Youth Soccer Ball (Micro-Soccer Ball)

Stage	Basic	Mature
Angular		
Velocity (deg/sec)		
Shank	671 (582)	805 (1056)
Thigh	572 (554)	602 (537)
Acceleration (deg/sec^2)		
Shank	7667 (8237)	6210 (8172)
Thigh	-4369 (-2095)	-7489 (-8393)

A number of the predicted trends at contact were found during an angled approach. The comparison between the Basic and Mature Stage performers' respective shank and thigh mean thigh angular velocities are illustrated further in Figure 14. The Basic Stage performers' results showed increasing angular velocities of the thigh and shank from backswing to contact. The Basic Stage performers exhibited similar velocities for the thigh and shank with the Micro-Soccer ball but had a greater shank angular velocity with the standard soccer ball. The Mature Stage performers had a greater difference in magnitude between the angular velocities of the thigh and shank when compared to the Basic Stage findings. Additionally, it is evident in the illustration of Figure 14, that the shank angular velocity of the Mature Stage subjects was greater with the Micro-Soccer ball than with the standard soccer ball.

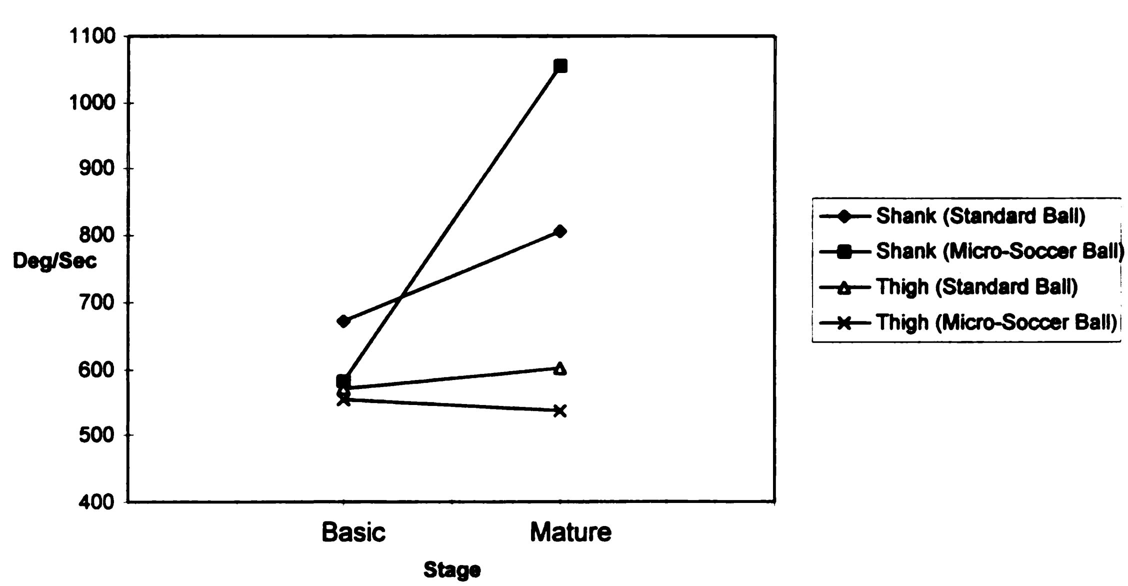

Figure 14. Basic and Mature Stage subjects' thigh and shank angular velocities at contact with the standard and Micro-Soccer balls.

Although the mean thigh velocities of the Mature Stage performers for both ball types was comparable to the Basic Stage mean thigh velocities, the Mature Stage subjects exhibited greater mean shank velocities relative to thigh velocities. Additionally, the angular velocity for the thigh of the Mature Stage subjects decreased when using the Micro-Soccer ball; perhaps explaining the sharp increase in magnitude of the shank angular velocity. These greater differences between thigh and shank velocities would have been expected for the Mature Stage, confirming the segmental relationship as discussed by Putnam (1993) and Glassow and Moritmer (1968). This difference between segmental velocities further highlighted the skill level difference associated with the two stages.

Both the Mature Stage and Basic Stage performers exhibited knee joint flexion at contact for both ball types. There may be other variables, such other body segment interactions, that could differentiate between skill levels during an angled approach kick. For example, arm and leg opposition, was a characteristic used to differentiate between skill levels in the study by Haubenstricker et al. (1981). It was outside the scope of this study to examine the relationships of other body segments to kicking.

<u>Follow through phase</u>

It was expected, and confirmed, that for the Basic Stage performers, knee flexion was maintained during the follow through phase as hip flexion occurred for both soccer ball types used. The Mature Stage performers exhibited greater hip flexion with the standard ball at 123^0 in comparison to 128^0 with the Micro-Soccer ball. The hip flexion of the Basic Stage performers was greater than that of the Mature Stage performers, but almost identical for both ball types used. The differences in hip joint angles between the Basic Stage and Mature Stage was likely a result of greater segmental velocities of the Mature Stage performers. All performers were found to extend the knee to approximately 176^0 with both ball types during the follow through phase. It was expected and found in the results that as skill level increased, the Mature Stage level subjects exhibited marked increase in hip flexion, and approached full extension of the knee joint. The cause of the greater hip flexion was most likely due to the increased segmental velocities throughout the kicking sequence. The increased segmental velocities of the Mature Stage subjects would result in increased momentum of the segments, causing marked flexion of the hip joint during follow through . The hip joint angles at follow through further differentiated the stages for the angled approach for both ball types. Finally, for both ball types, all of the Mature Stage performers were airborne during the follow through phase while the Basic Stage performers were not. Figure 15 provided an illustrated overview of the relationship between the hip and knee joints of the Basic and Mature Stage subjects at maximum forward movement.

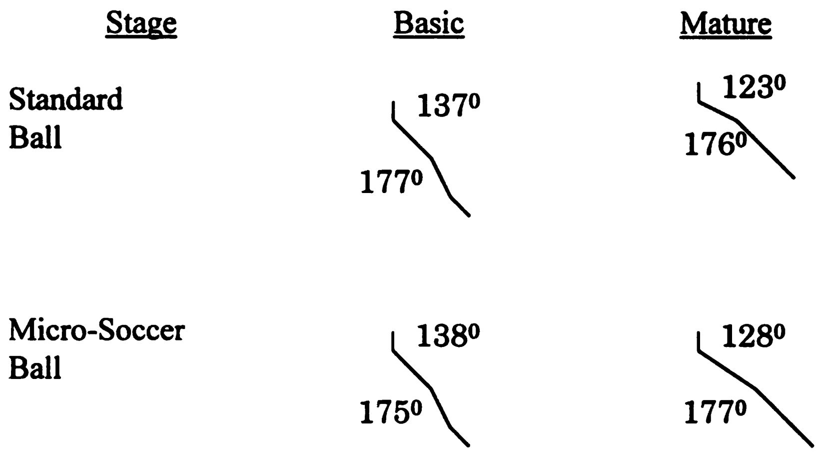

Figure 15. Mean hip and knee joint angles at maximum forward movement for Basic and Mature Stages.

Segment timing and coordination

The results of the current study revealed a difference in the timing and coordination of the shank and thigh. The expected segmental relationship, or the soccer paradox, between the thigh and shank of a randomly selected Mature Stage subject is illustrated for both a standard youth soccer ball and the Micro-Soccer ball in Figure 16 and 17, respectively. From maximum backswing of the kicking leg (MBS), both the thigh and the shank increased in velocity, as illustrated by the increase in the slopes of the curves (Figure 16). This increased velocity of both segments corresponded to the initial force production phase of the kick. As the velocity of both segments increased, at 0.034 sec prior to contact (frame 21), the thigh reached its peak velocity and began decreasing in velocity, as indicated by the downward sloping curve.

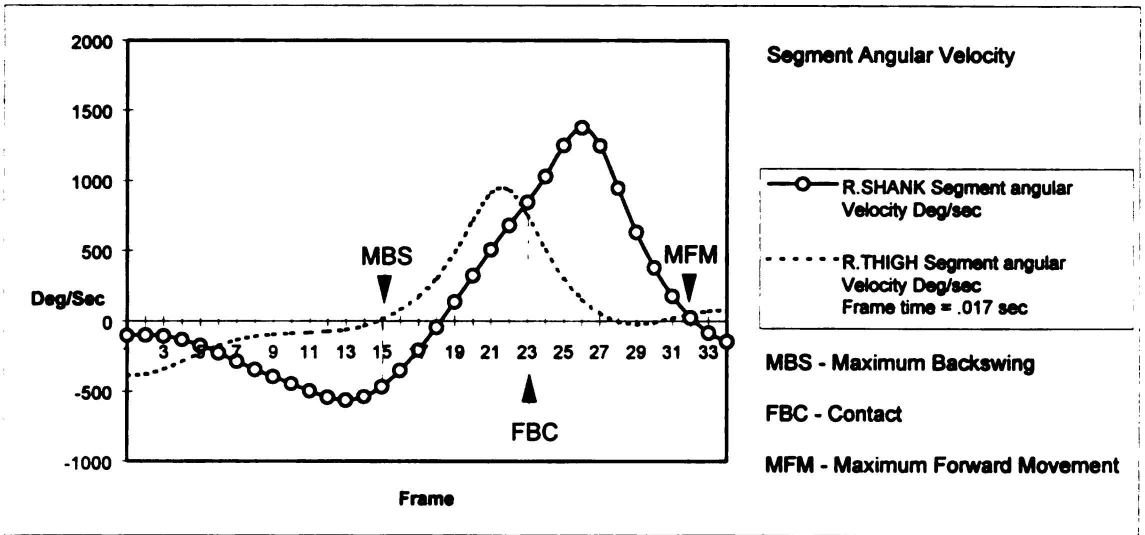

Figure 16. Mature Stage performer shank and thigh relationship using a standard youth soccer ball.

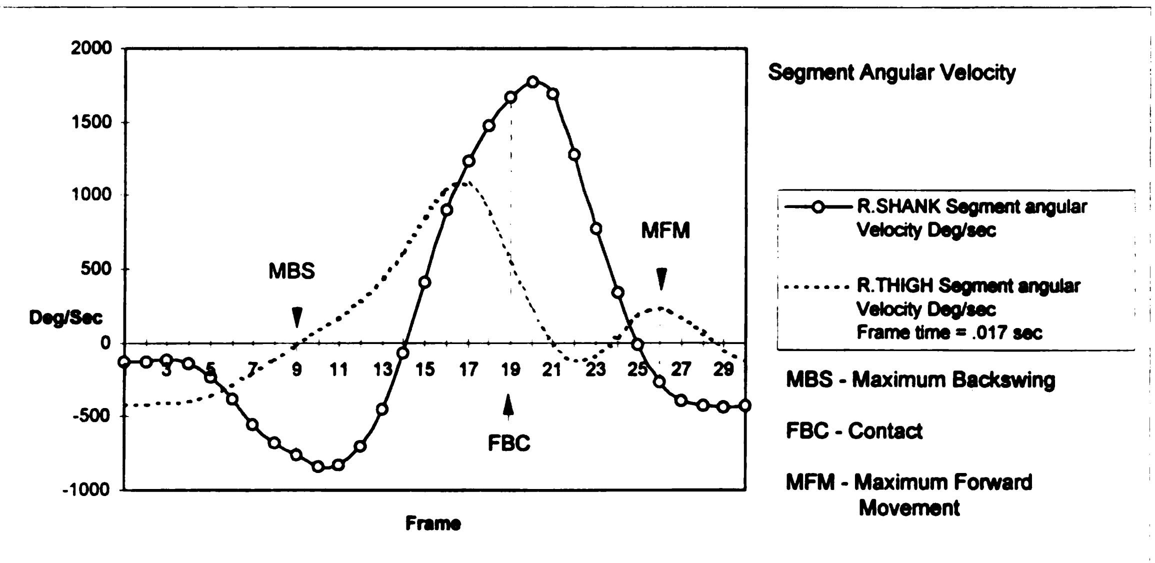

Figure 17. Mature Stage performer shank and thigh relationship using a Micro-Soccer ball.

At contact (FBC), the thigh continued its decrease in velocity, while the shank continued increasing in velocity. This increase in shank velocity continued for 0.034 sec (3 frames) following contact. At that time, frame 26, the shank reached its peak and decreased in velocity until maximum forward movement. A slight increase in thigh velocity began in follow through at frame 29.

This slight increase in velocity for the thigh indicated that the momentum of the shank caused the thigh to increase in velocity during the follow through. At maximum height of the kicking foot (MFM), the velocity of the thigh and shank both reached approximately zero deg/sec, indicating the end of force dissipation.

The reader is directed to Figure 17, where thigh and shank relationships for a Mature Stage performer with the Micro-Soccer ball are illustrated. At maximum backswing (MBS), the thigh increased in velocity while the shank decreased. This decrease in shank angular velocity occurred for approximately 0.017 seconds (one frame) past maximum backswing, followed by an increase in velocity that lasted past contact. Approximately 0.034 seconds (two frames) prior to contact, the thigh began to decrease its velocity. The shank however, continued increasing in velocity to and through contact, by one frame, as illustrated by the increasing slope of the curve from contact (FBC) to the peak velocity for the shank. The thigh reached its post contact minimum velocity at approximately frame 22, .034 seconds (two frames) after peak velocity of the shank. It was at frame 23 that a second increase in velocity of the thigh was noted. This secondary increase in velocity, was not as pronounced with the angled approach using the standard ball, as with the Micro-Soccer ball. This secondary increase in velocity (Figure 17) of the thigh was thought to be the result of the momentum of the shank causing the thigh to make a spatial adjustment as a result of the airborne portion of the follow through phase.

At contact, the shank velocity was approximately 850 deg/sec using the standard youth soccer ball (Figure 16), while for the Micro-Soccer ball it was approximately 1700 deg/sec (Figure 17). This 850 deg/sec difference in velocity at contact could explain the secondary increase in velocity of the thigh during the follow through phase. The shank had a greater amount of momentum which caused the anterior rotation of the thigh, seen as an increase in hip joint flexion, during follow through. This relationship, which was found for the Mature Stage subjects, indicated a more mature pattern as predicted by the current study and as was discussed by Putnam (1991 and 1993) and Glassow and Mortimer (1968).

Additionally, one must consider that less force was needed to overcome the resting inertia of the Micro-Soccer ball than the standard soccer ball, since the Micro-Soccer ball weighed 26% less than the standard soccer ball. With weight and mass being proportional, the 850 deg/sec difference at contact in the shank angular velocities between both soccer balls, also could have been attributed to the difference in inertia of each respective ball.

The following predicted trends for the angled approach were found in the current study for both ball types. As predicted, during the preparatory phase, the Basic Stage performers placed the foot of the support leg along the angled approach line, while the Mature Stage performers placed their support foot along the path of the intended flight of the ball. This foot placement assisted in differentiating between the two skill levels. Additionally, no hip hyperextension was found for either stage, and the knee of the respective kicking legs was flexed at maximum backswing. At contact, the Basic Stage performers exhibited increasing angular velocities of the thigh and shank, as predicted. The Mature Stage performers exhibited the segmental relationship (soccer paradox), where the thigh decreased in velocity while the shank continued to increase in velocity just prior to contact. The Basic Stage performers also exhibited similar actions that could be characterized as an elementary form of the soccer paradox. Knee flexion was found at contact for both stages. The knee was almost fully extended at maximum forward movement for all performers. Also, the Mature Stage subjects exhibited greater hip flexion at maximum forward movement and maintained knee flexion during the follow through phase than the Basic Stage, subjects as predicted. Finally, as predicted, all of the Mature Stage subjects were airborne during the follow through phase.

Segment rotation differences between stages three and four

The theories pertaining to segmental relationships developed by Putnam (1993) were based on adult athletes. One purpose of this study was to identify differences in rotations of the thigh, as well as the shank, of the kicking limb between subjects exhibiting stages three and four while kicking a standard youth soccer ball. In the current study, it was hypothesized that the stage four subjects would exhibit a more mature pattern with the kicking limb than the stage three subjects. From the literature, this more mature pattern would be indicated by rotation of the thigh dominating the initial part of the force production phase with minimal rotation about the knee joint. Furthermore, in the later phase of the force production phase, thigh rotation would decrease as shank rotation increased to ball contact. The statistical method employed to determine significant differences was a balanced design analysis of variance (ANOVA, $p < .10$).

The selected kinematic variables of mean angular velocities and mean angular accelerations of the shank and thigh, for the stage three and stage four performers were compared against each other in order to determine if significant differences existed between the variables tested. There were no significant differences at maximum backswing between stages three and four in the variables of angular velocity and acceleration for the thigh, as well as the shank (Table 12). At maximum backswing the thigh may have stopped prior to beginning its forward movement or may have just begun its initial forward movement, whereas the shank would have stopped or finished its flexion. Therefore, if this period were truly maximum backswing, there should be no significant difference, even though the thigh angular velocities and accelerations were not at zero.

Table 12

ANOVA: Stage Effect on Mean Angular Velocity and Mean Angular Acceleration for Stage Three and Four Subjects at Maximum Backswing

Analysis of Variance for Angular Velocity of the Shank

Source	DF	SS	MS	F	P
Stage	1	40986	40986	1.66	0.218
Error	14	345358	24668		
Total	15	386344			

Analysis of Variance for Angular Velocity of the Thigh

Source	DF	SS	MS	F	P
Stage	1	10936	10936	0.79	0.389
Error	14	193898	13850		
Total	15	204834			

Analysis of Variance for Angular Acceleration of the Shank

Source	DF	SS	MS	F	P
Stage	1	205028	205028	0.01	0.906
Error	14	200395887	14313992		
Total	15	200600915			

Analysis of Variance for Angular Acceleration of the Thigh

Source	DF	SS	MS	F	P
Stage	1	22021668	22021668	1.72	0.211
Error	14	179086457	12791890		
Total	15	201108125			

$p < .10$

At ball contact, the stage four performers were found to be significantly different from the stage three performers with respect to angular velocity of the shank ($F = 7.28$, $p = .017$) and the angular acceleration of the thigh ($F = 12.38$, $p = .003$). There was not a significant difference in the angular velocity of the thigh ($F = .26$, $p = .615$), nor in the angular acceleration of the shank ($F = .83$, $p = .377$) between the stage three and four subjects (Table 13).

Table 13

ANOVA: Stage Affect on Angular Velocity and Acceleration at Contact

Analysis of Variance for Angular Velocity of the Shank

Source	DF	SS	MS	F	P
Stage	1	730298	730298	7.28	0.017*
Error	14	1404893	100349		
Total	15	2135191			

Analysis of Variance for Angular Velocity of the Thigh

Source	DF	SS	MS	F	P
Stage	1	3994	3994	0.26	0.615
Error	14	211701	15122		
Total	15	215695			

Analysis of Variance for Angular Acceleration of the Shank

Source	DF	SS	MS	F	P
Stage	1	20322515	20322515	0.83	0.377
Error	14	341105499	24364679		
Total	15	361428014			

Analysis of Variance for Angular Acceleration of the Thigh

Source	DF	SS	MS	F	P
Stage	1	87719146	87719146	12.38	0.003*
Error	14	99203397	7085957		
Total	15	186922544			

*$p < .10$

The stage four subjects' significantly greater shank angular velocity and significantly greater deceleration of the thigh at contact highlighted their increased skill level in comparison to the stage three subjects. The significant differences found in the angular velocities of the shank as well as angular accelerations of the thigh at contact indicated that the stage four subjects were better able to utilize the segmental relationships in performing the kick resulting in a more coordinated pattern. This explanation does agree with the discussions of segment coordination by Putnam (1983) and Glassow and Mortimer (1968). The significant differences found between angular velocity of the shank and angular acceleration of the thigh for stages three and four subjects using a direct approach, may be a result of increased coordination and timing over the less mature stage three subjects.

A comparison between the rotations of the shank, as well as the thigh, during the follow through phase indicated a significant difference in the shank angular velocity ($F = 6.41$, $p = .024$) and the thigh angular velocity ($F = 6.16$, $p = .026$) between stages three and four (Table 14). The stage four subjects exhibited decreasing velocity of the shank, indicating knee flexion, and increasing thigh velocity, indicating hip flexion. In contrast the stage three subjects exhibited increased shank velocity, indicating knee extension, and a decrease in thigh angular velocity, indicating less hip flexion. These differences in velocities were probably a result of the stage four performers being airborne at maximum forward movement of the kicking foot, which would require different spatial adjustments to be made relative to the stage three subjects. While the stage four subjects were airborne, the length of the leg moment arm may have required adjustment for the purpose of balance and timing. However, examining the moment arm length relative to balance of the body was outside the scope of this study.

Table 14

ANOVA: Stage Effect on Angular Velocity and Acceleration at Maximum Forward Movement

Analysis of Variance for Angular Velocity of the Shank

Source	DF	SS	MS	F	P
Stage	1	108455	108455	6.41	0.024*
Error	14	236969	16926		
Total	15	345424			

Analysis of Variance for Angular Velocity of the Thigh

Source	DF	SS	MS	F	P
Stage	1	48819	48819	6.16	0.026*
Error	14	110966	7926		
Total	15	159785			

Analysis of Variance for Angular Acceleration of the Shank

Source	DF	SS	MS	F	P
Stage	1	320582	320582	0.02	0.893
Error	14	238990453	17070747		
Total	15	239311035			

Analysis of Variance for Angular Acceleration of the Thigh

Source	DF	SS	MS	F	P
Stage	1	4031562	4031562	0.81	0.384
Error	14	69751394	4982242		
Total	15	73782956			

*p < .10

The hypothesis that there would be significant differences in the rotations of the thigh as well as the shank of the kicking limb between subjects exhibiting stages three and four while kicking a standard youth soccer ball using a direct approach was rejected. A comparison between stages three and four with respect to relative angular velocities and accelerations was provided in Table 15. Significant differences between stages three and four were found only with respect to the angular velocity of the shank at contact and angular acceleration of the thigh at contact. Also, significant differences were determined with respect to angular velocity of the shank at maximum forward movement, and angular velocity of the thigh at maximum forward movement. The significant differences between stages three and four indicated the higher skill level of the stage four subjects with respect to the angular velocity of the shank and angular acceleration of the thigh. The significantly greater shank angular velocity and lower thigh angular acceleration at contact are in accordance with the literature pertaining to skilled kickers.

Table 15

Angular Velocity and Acceleration Comparisons Between Stage Three and Four

	Stage 3	Stage 4	
Maximum Backswing			
Shank	ω	$>\omega$	
Thigh	ω	$<\omega$	
Shank	α	$>\alpha$	
Thigh	α	$>\alpha$	
Contact			
Shank	ω	$>\omega$ *	
Thigh	ω	$<\omega$	
Shank	α	$<\alpha$	
Thigh	α	$<\alpha$ *	
Maximum Forward Movement			
Shank	ω	$<\omega$ *	
Thigh	ω	$>\omega$ *	
Shank	α	α	(ω = angular velocity)
Thigh	α	$<\alpha$	(α = angular acceleration)

*$p < .10$

When the segmental angular velocities were examined graphically, (Figures 18 and 19) a timing difference seemed to exist between stage three and stage four performers. For discussion purposes, one data set for angular velocity and acceleration

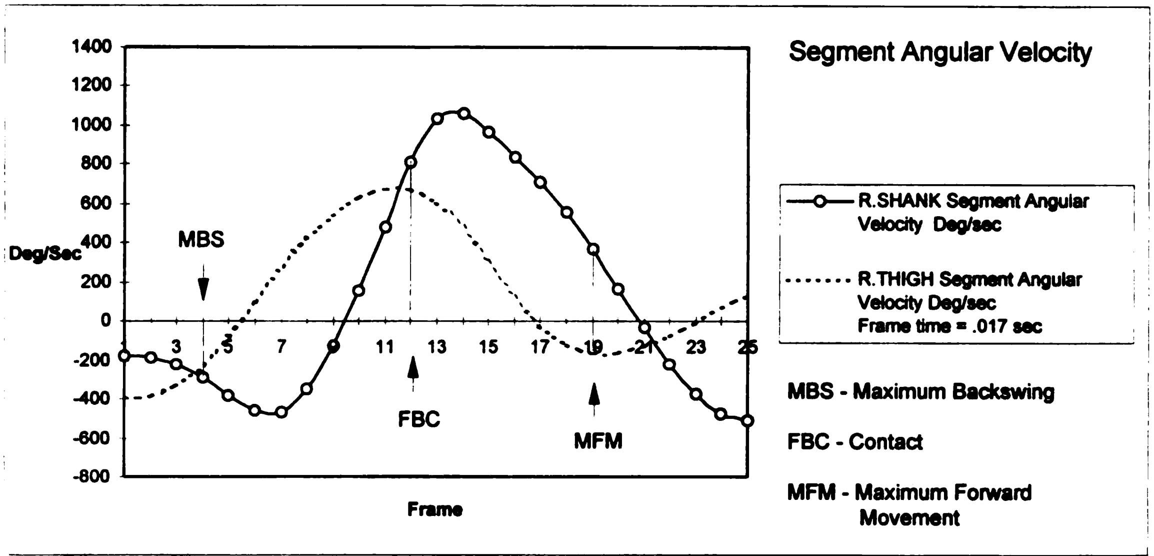

Figure 18. Stage three performer using a direct approach while kicking a standard youth soccer ball.

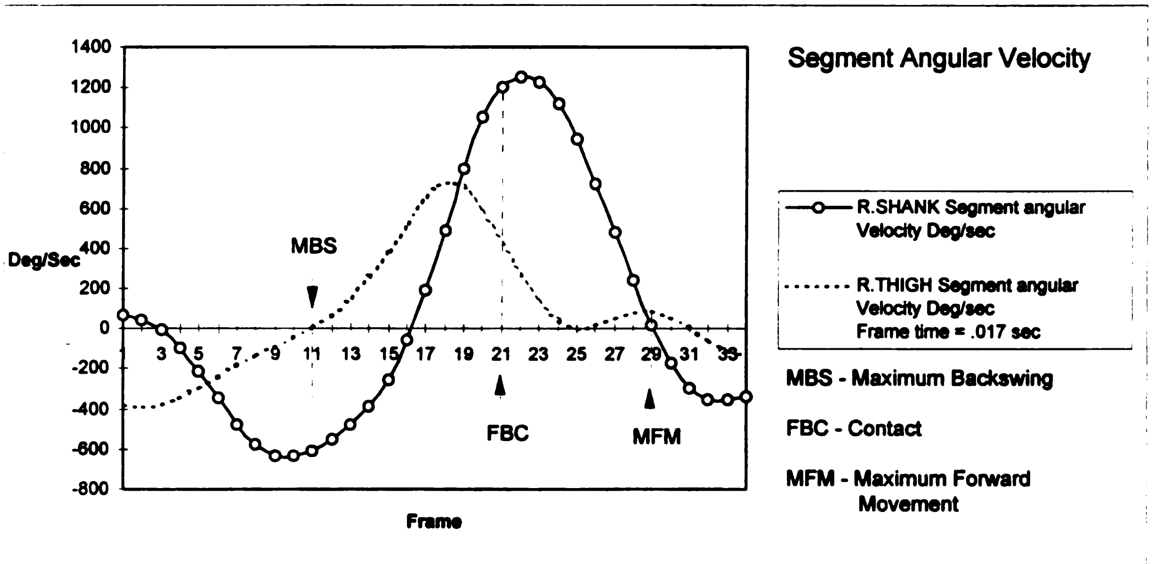

Figure 19. Stage four performer using a direct approach while kicking a standard youth soccer ball.

were randomly chosen from each stage three and stage four data sets. A stage three subject's data for kicking is illustrated in Figure 18. At maximum backswing (MBS), the thigh is shown to be increasing in angular velocity, whereas the shank is shown to be decreasing in velocity. The decrease in the shank angular velocity may have indicated that the timing of forward movement of the thigh caused the shank to rotate posteriorly resulting in knee flexion (Putnam, 1993). At approximately frame seven, both the thigh and shank were increasing in velocity toward contact. At 0.017 seconds (one frame) prior to contact (Figure 18, frame 11), the thigh reached its peak velocity and began to decrease in velocity. The shank continued its increase in velocity up to and following contact for 0.034 seconds (two frames), before beginning its decrease in velocity. From the peak angular velocity of the shank (Figure 18, frame 14), both the shank and the thigh decreased in velocity to maximum forward movement of the kicking foot (MFM). The maximum forward movement indicated the end of the kicking sequence for the stage three subject. At that point, (MFM), the thigh appeared to have a constant velocity for 0.017 seconds (one frame), while the shank continued its decrease in velocity.

The data for a stage four subject, illustrated in Figure 19, shows increasing thigh as well as shank velocities from maximum backswing to 0.051 seconds (three frames) prior to contact, where the thigh segment peaked in velocity (frame 18). Then the thigh began to decrease in velocity (Figure 19, frame 19), while the shank continued to increase in velocity for 0.068 seconds (four frames) one frame past contact, as the thigh decreased in velocity. The decrease in thigh velocity with an increase in shank velocity was representative of the soccer paradox. Thigh velocity decreased for 0.068 seconds (four frames) following contact, before increasing in velocity. The secondary increase in velocity found for the thigh (frame 26) of the stage four subject in Figure 19, was also seen in the stage three subject. This secondary increase most likely resulted because of the increased angular velocity of the shank following contact. The stage four performer made a spatial adjustment while being airborne during the follow through phase. After shank peak velocity, the shank decreased in velocity for 0.119 seconds (seven frames) to maximum forward movement. At the end of the kicking sequence (MFM), the thigh was at its secondary peak and the shank was decreasing in velocity at maximum forward movement.

The stage three performer in Figure 18 exhibited a shorter period of time from maximum backswing to contact (0.136 sec) than did the stage four performer in Figure 19 (0.17 sec). The force production phase of the stage four performer occurred over a greater time period than for the stage three performer, in which the leg segments accelerated forward prior to ball contact, resulting in the distal segment reaching a greater velocity at ball contact (1200 deg/sec) than did the stage three performer (800 deg/sec). The Mature Stage subject's shank was already increasing in velocity at maximum backswing, unlike the Basic Stage subject where it was decreasing in velocity. This difference in timing may have been as a result of the Basic Stage subject's shank "lagging" behind the forward movement of the thigh. The segmental relationships were found in the stage three and four performers. The soccer paradox exhibited by the stage four subjects at contact can be explained by the momentum of the shank. The segmental relationship exhibited in the current study coincided with the concepts as discussed by Putnam (1983 and 1993). A final difference was that maximum thigh velocity occurred closer to contact (0.017 sec, one frame) for the stage three performer than for of the stage four performer (0.051 sec, three frames). This likely indicated that the stage four performer's coordination of the segments was more skilled.

The angular acceleration data, for the same stage three performer and stage four performer used in Figures 18 and 19, are illustrated in Figures 20 and 21. At maximum backswing, the stage three performer showed an increase in thigh angular acceleration and a decrease in shank acceleration. This acceleration of the thigh lasted approximately 0.034 seconds (two frames) while deceleration of the shank lasted approximately 0.017 seconds (one frame) following maximum backswing. At frame six, the thigh of the stage three performer began to decelerate, and continued decelerating four frames past contact. During the thigh deceleration the shank continued to accelerate to 0.017 seconds (one frame) prior to contact. Relatively large accelerations were illustrated in Figure 20 from frame six to frame eight for the stage three subject and were exhibited by the steep slope between the frames. The large magnitude in the shank acceleration was attributed to a rapid knee extension from maximum backswing to ball contact. At contact, both the thigh and the shank were decelerating. Also noted, was the fairly rapid deceleration of the shank following contact from frame 12 to frame 14 (Figure 20) seen as steep negative slopes.

Even though the graph of angular velocity (Figure 18, frame 12) showed an increase in shank velocity prior to contact, the rate at which the velocity was changing was not as great as the preceding frame. This relatively smaller rate of change of velocity resulted in the deceleration of the shank. Rapid decelerations at contact were due primarily to overcoming the inertia of the ball at contact.

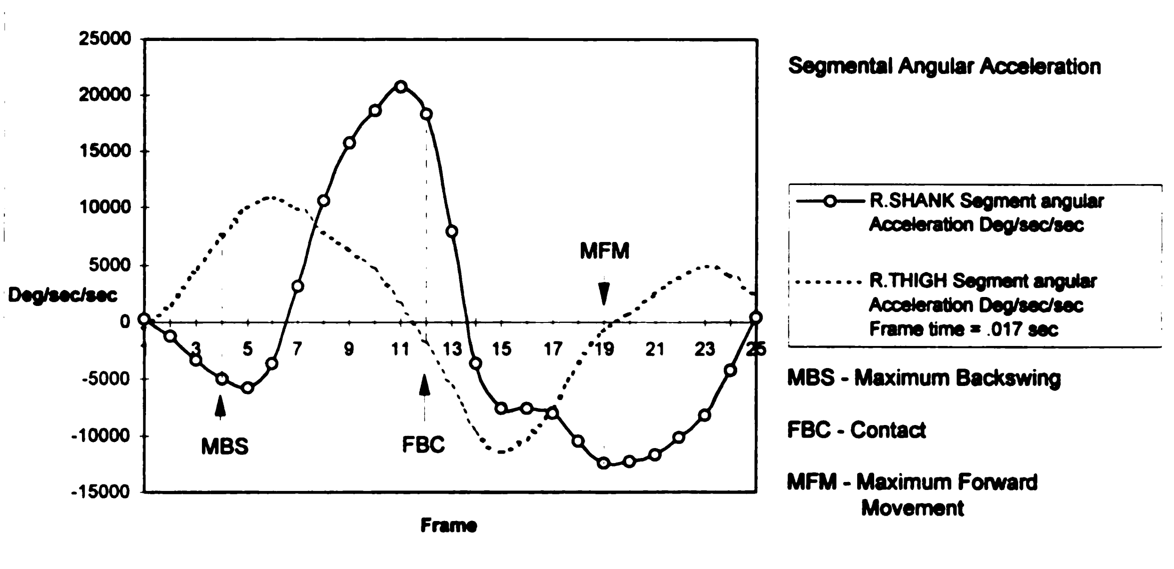

Figure 20. Angular acceleration of the thigh and shank of a stage three performer using a standard youth soccer ball.

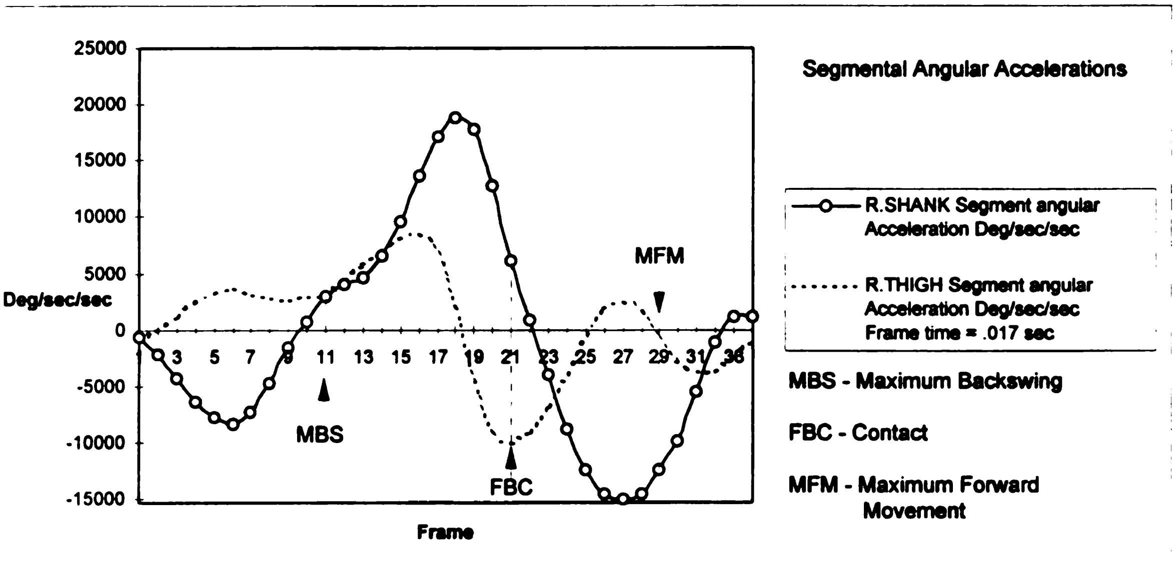

Figure 21. Angular acceleration of the thigh and shank of a stage four performer using a standard youth soccer ball.

Following contact, a deceleration of the shank continued to maximum forward movement of the foot. The thigh began a secondary acceleration, after contact at frame 15, which was approximately 0.068 seconds (four frames) after the peak angular acceleration of the shank. The secondary acceleration of the thigh (Figure 20, frame 15) was accompanied by a brief, relatively constant acceleration of the shank (Figure 20, frames 15 through 17). The momentum of the shank, was probably responsible for the thigh accelerating to the position of maximum forward movement of the kicking foot (frame 19 of Figure 20).

The acceleration data for the stage four subject previously examined, is illustrated in Figure 21. A different timing of accelerations and decelerations for the segments was exhibited. From maximum backswing (MBS) to peak angular acceleration of the thigh (0.085 seconds, five frames), the thigh and shank both accelerated. At frame 16 of Figure 21, the thigh peaked and then began to decelerate, as the shank continued accelerating to its maximum angular acceleration for an additional 0.034 seconds (two frames).

At contact (FBC), the thigh had reached its greatest deceleration, as the shank continued decelerating (frame 21, Figure 21). Following contact, the shank continued its deceleration for 0.102 seconds (six frames), as the thigh accelerated for approximately the same period of time. From approximately frame 27 of Figure 21, the thigh decelerated for 0.034 seconds (two frames), while the shank accelerated for the same period of time. The changes in shank acceleration from frame 27 to the end of the kicking sequence at maximum forward movement of the kicking foot, were potentially due to a spatial adjustment while the stage four performer was in flight. Shortening of the relative moment arm of the kicking leg during the airborne stage of the follow through may have resulted in acceleration of the shank. The specific timing of this adjustment was not studied in the current investigation.

Deceleration of the thigh for the stage three subject occurred over a longer period of time (0.153 seconds) than did the deceleration of the thigh of the stage four subject (0.085 seconds) from peak angular acceleration. The magnitude of the stage three subject's deceleration (Figure 20, frames 6 to 12) was greater (22,426 deg/sec^2) than that of the stage four subject's deceleration (18,598 deg/sec^2, frames 16 to 21). The difference in the time periods and magnitudes of deceleration can be attributed to the increased coordination and timing of the stage four subject, which caused the performer to become airborne. The greater rate of deceleration of the thigh prior to contact exhibited by the stage four subject compared with the stage three subject, could have been because the stage four subject was airborne. Once airborne, in the follow through phase, the stage four performer needed to position the kicking leg for landing. As in Haubenstricker et al. (1981) and Barfield (1995), if the momentum of the subject is sufficient enough following contact, the result may be an airborne phase and the subject may land on the kicking foot, instead of the support foot. The ability to land on the kicking foot further differentiated between more advanced skill levels. In the current study, none of the stage three subjects landed on the kicking leg foot.

At contact, the thigh of the selected stage four performer was seen to exhibit the characteristic of thigh deceleration prior to contact found in the literature for skilled kickers (Putnam, 1993; Glassow and Mortimer, 1968). The stage four performer exhibited greater thigh deceleration closer to contact (Figure 21, frames 16 to 21) than did the stage three performer (Figure 21, frame 6 to 12), illustrated by the steeper negative slope for the stage four subject. This difference in thigh deceleration, was attributed to the differences in the peak angular velocities of the stage four subjects which resulted in increased momentum of the shank. According to Putnam (1993) the greater momentum of the shank caused a greater deceleration of the thigh for the stage four subject at contact due to a more ballistic movement of the shank.

Direct approach versus angled approach

The angled approach observed in skilled soccer players was approximately 45^0 to the ball (Douge, 1988; Isokaw and Lees, 1988). Researchers who studied the angled approach (Plagenhoef, 1971; Isokawa and Lees, 1988; Barfield, 1995) indicated that an angled approach resulted in increased performance when compared to a direct approach. This increased performance was measured by higher ball velocity and angle of ball projection following contact. The higher ball velocity was caused by the pelvis and leg being carried through a greater range of motion. These greater ranges of motion allowed for the development of increased leg segment velocities. The greater range of motion of the angled approach involved a greater number of muscle groups due to preparatory movements of the hip joint and pelvic girdle. The increased number of muscle groups and greater ranges of motion contributed to increased muscle forces which can result in increased segment velocities and subsequent higher ball velocities. However, literature relating to children's performance of a kick during the developmental years, or to segmental differences using an angled approach has not been found. One purpose of this study was to determine if significant differences existed in the shank, as well as the thigh, angular velocities and accelerations for subjects, between a direct approach and an angled approach while kicking a standard youth soccer ball. It was hypothesized that there would be significant differences in rotations of the thigh, as well as the shank of the kicking limb of the subjects using a direct approach when compared with subjects using an angled approach, while kicking a standard youth soccer ball.

The angular velocities and accelerations for the thigh, as well as the shank, of performers using direct and angled approaches were treated statistically with a balanced design ANOVA ($p < .10$). The three points of interest in the kick, maximum backswing, contact, and maximum forward movement were analyzed. The differences between the two approaches with respect to shank angular velocity were not significantly different at maximum backswing ($F = .05$, $p = .825$; Table 16). In addition, thigh angular velocity comparisons between the direct approach and the angled approach were found not to be significantly different ($F = .17$, $p = .687$). Moreover, the differences between the two approaches with respect to the angular accelerations of the shank segment were found not significant ($F = .60$, $p = .446$). Finally, the differences between the two approaches with respect to angular acceleration of the thigh were found not significant ($F = .01$, $p = .917$). As a result of the current study, the angular velocities and accelerations of the shank and thigh at maximum backswing were found to be not significantly different between the direct approach and the angled approach.

At maximum backswing, the thigh may have almost stopped prior to beginning its forward movement or may just have begun its initial forward movement. At maximum backswing, the shank would have been finishing its motion. Therefore, if this period were truly maximum backswing, there should be no significant differences, even though the thigh and shank angular velocities and accelerations were not zero.

Table 16

ANOVA: Approach Effect on Angular Velocity and Angular Acceleration for the Thigh and Shank at Maximum Backswing

Analysis of Variance for Angular Velocity of the Shank

Source	DF	SS	MS	F	P
Approach	1	1426	1426	0.05	0.825
Error	30	858934	28631		
Total	31	860360			

Analysis of Variance for Angular Velocity of the Thigh

Source	DF	SS	MS	F	P
Approach	1	2198	2198	0.17	0.687
Error	30	397494	13250		
Total	31	399691			

Analysis of Variance for Angular Acceleration of the Shank

Source	DF	SS	MS	F	P
Approach	1	24522930	24522930	0.60	0.446
Error	30	1234673665	41155789		
Total	31	1259196595			

Analysis of Variance for Angular Acceleration of the Thigh

Source	DF	SS	MS	F	P
Approach	1	119353	119353	0.01	0.917
Error	30	323005647	10766855		
Total	31	323124999			

$p < .10$

At ball contact, only the angular acceleration of the shank was found significantly different ($F = 4.45$, $p = .043$) between the two approaches. In contrast, there were no significant differences between the two approaches with respect to the angular velocities of the shank and thigh, nor angular acceleration. These ANOVA results are reported in Table 17.

Table 17

ANOVA: Approach Effect on Angular Velocity and Angular Acceleration for the Thigh and Shank at Contact

Analysis of Variance for Angular Velocity of the Shank

Source	DF	SS	MS	F	P
Approach	1	15891	15891	0.13	0.718
Error	30	3576135	119205		
Total	31	3592026			

Analysis of Variance for Angular Velocity of the Thigh

Source	DF	SS	MS	F	P
Approach	1	643	643	0.03	0.868
Error	30	682097	22737		
Total	31	682740			

Analysis of Variance for Angular Acceleration of the Shank

Source	DF	SS	MS	F	P
Approach	1	162709074	162709074	4.45	0.043*
Error	30	1097401444	36580048		
Total	31	1260110519			

Analysis of Variance for Angular Acceleration of the Thigh

Source	DF	SS	MS	F	P
Approach	1	36924766	36924766	2.54	0.122
Error	30	436844125	14561471		
Total	31	473768891			

*$p < .10$

The significant difference found between the approaches with respect to the angular acceleration of the shank was likely due to greater shank acceleration caused by the increased difficulty of the angled approach. Overall, the angular acceleration of the shanks were lower for the angled approach versus the direct approach, as opposed to the expected findings of greater shank angular acceleration due to the greater range of motion through which the leg was carried. Even though both groups completed the angled approach, the lack of experience using this approach by the subjects may have had an effect on the performance of the kick. The subjects may have been concentrating more on the task of completing the kick using the angled approach, instead of kicking the ball as forcefully as possible.

No significant differences between the approach types were found when comparisons were made at maximum forward movement of the kicking foot. At maximum forward movement, because the foot would have reached its peak height, the thigh may have almost stopped prior to beginning its backward movement or may have begun its initial backward movement. The shank would have been stopped or finished its extension at the knee. Therefore, if this period were truly maximum forward movement, there should be no significant differences, even though the thigh and the shank velocities and accelerations were not zero. The position at maximum forward movement may be similar for any kicker in any stage, and may account for the lack of significance at maximum forward movement. The variables of angular velocity and acceleration of the thigh, as well as the shank, for maximum forward movement are presented in Table 18. The hypothesis that there will be a difference in the rotations of the thigh, as well as the shank, of the kicking limb of the subjects using a direct approach when compared with subjects using an angled approach, while kicking a standard youth soccer ball was rejected.

Table 18

ANOVA: Approach Effect on Angular Velocity and Angular Acceleration for the Thigh and Shank at Maximum Forward Movement

Analysis of Variance for Angular Velocity of the Shank

Source	DF	SS	MS	F	P
Approach	1	4522	4522	0.21	0.647
Error	30	635079	21169		
Total	31	639601			

Analysis of Variance for Angular Velocity of the Thigh

Source	DF	SS	MS	F	P
Approach	1	29464	29464	1.04	0.317
Error	30	853360	28445		
Total	31	882824			

Analysis of Variance for Angular Acceleration of the Shank

Source	DF	SS	MS	F	P
Approach	1	21196398	21196398	0.96	0.335
Error	30	662350515	22078350		
Total	31	683546912			

Analysis of Variance for Angular Acceleration of the Thigh

Source	DF	SS	MS	F	P
Approach	1	638761	638761	0.12	0.735
Error	30	163802657	5460089		
Total	31	164441418			

*$p < .10$

Illustrated in Table 19 was an overview of the differences between the direct and angled approaches with respect to the angular velocities and accelerations of the shank, as well as the thigh, for the current study.

Table 19

Angular Velocity and Acceleration Comparisons Between the Direct and Angled Approach

	Direct	Angled	
Maximum Backswing			
Shank	ω	$<\omega$	
Thigh	ω	$<\omega$	
Shank	α	$<\alpha$	
Thigh	α	$>\alpha$	
Contact			
Shank	ω	$<\omega$	
Thigh	ω	$>\omega$	
Shank	α	$<\alpha$ *	
Thigh	α	$<\alpha$	
Maximum Forward Movement			
Shank	ω	$>\omega$	
Thigh	ω	$>\omega$	
Shank	α	$<\alpha$	(ω angular velocity)
Thigh	α	$<\alpha$	(α angular acceleration)

*$p < .10$

In the current study, the performers most likely experienced difficulty in completing the angled approach due to a lack of experience with this approach. The only variable found to be significantly different between the approaches was angular acceleration of the shank at contact. Additionally, the angular acceleration of the shank was less for the Mature Stage performers than for the Basic Stage performers. These findings may be due to the inexperienced subjects concentrating on the task of completing the kick, instead of kicking the ball as forcefully as possible.

Standard youth soccer ball versus the Micro-Soccer ball

A light weight soccer ball developed for children was used in this study. The developers of the Micro-Soccer ball theorized that kicking performance would be increased, as shown by increased ball velocity. The final hypothesis for this study stated that the resultant velocity of the lightweight soccer ball would be greater than that of the standard youth soccer ball regardless of approach. Resultant ball velocity was determined as the initial velocity (V_o) of the ball as it left the foot. A balanced design ANOVA ($p < .10$) was used to test the above hypothesis.

The stage three and four subjects obtained greater initial ball velocity (V_o) with the Micro-Soccer ball at 9.03 and 14.24 m/sec, respectively. These initial velocity values corresponded well with Luhtanen's (1988) findings of initial velocity in his study of children. The stage three subjects' mean initial ball velocities differed by 1.56 m/sec between the two ball types, whereas the stage four subjects' mean initial ball velocities differed by 2.57 m/sec. The actual initial ball velocities between the ball types and across the stages used in the current study are presented in Table 20.

Table 20

Initial Ball Velocities Using a Direct Approach

	Stage	1	2	3	4
Ball					
Standard	Vo(m/sec)	3.46	4.12	7.46	11.66
Micro-Soccer	Vo(m/sec)	3.17	4.59	9.03	14.24

For the angled approach, the initial velocity differences between the standard youth soccer ball and Micro-Soccer ball, favored the Micro-Soccer ball. The difference in initial velocities between the two ball types was .64 m/sec for the stage three performers and 2.16 m/sec for the stage four subjects. The minimal differences in the initial velocities (V_o) of the Basic Stage subjects were likely the result of a lower skill level than that of the Mature Stage subjects. This lower skill level is illustrated in the velocity and acceleration graphs discussed earlier. Therefore, they may have concentrated on the task of completing the kick and not on kicking the ball as hard as possible. The initial velocities for the angled approach for both ball sizes and both levels used in the current study were are reported in Table 21.

Table 21

Initial Ball Velocities Using an Angled Approach

Ball	Stage	1	2	3 (Basic)	4 (Mature)
Standard	Vo(m/sec)	*	*	8.26	10.45
Micro-Soccer	Vo(m/sec)	*	*	8.90	12.62

Resultant ball velocities were examined for both approaches. For both approaches, resultant ball velocities were significantly different between the Micro-Soccer ball and the standard youth soccer ball ($F = 5.25$, $p = .025$). The use of the light weight ball resulted in greater initial velocities of the ball regardless of the approach used, than for the standard soccer ball (Table 22). However, no significant difference was found between the approach used and ball velocity (F = .45, p = .503).

Table 22

Analysis of Variance for Ball Velocity

Source	DF	SS	MS	F	P
Ball	1	497589	497589	5.25	0.025*
Approach	1	43087	43087	0.45	0.503
Error	61	5782358	94793		
Total	63	6323035			

*p < .10

Of interest, was the maximum ball velocity reported by Luhtanen (1988). Luhtanen stated that the 9-12 year old subjects in his study obtained ball velocities of 14.90 m/sec. He used a 450 gram ball for the 9-12 year old subjects which was heavier than the Micro-Soccer ball used in the current study, which weighed 260.93 grams. The stage one subjects obtained a greater velocity with the standard youth soccer ball at 3.46 m/sec, compared to the Micro-Soccer ball at 3.17 m/sec. However, the stage two, three, and four subjects obtained greater ball velocities with the Micro-Soccer ball at 4.59, 9.03, and 14.24 m/sec, respectively. Due to the small sample size for the stage one subjects, the greater ball velocity of the standard ball could be attributed to random variation. The stage four performers (three to eight years of age) in the current study using a direct approach, obtained a velocity of 14.24 m/sec, which was comparable to the 14.90 m/sec velocity obtained for the 9-12 year old subjects used by Luhtanen. Therefore, if resultant ball velocity were used as a performance measure, then the Micro-Soccer ball did improve performance, and its use would be beneficial to young soccer players.

Post filming interview

The assumption was made that as a result of each performer handling the two balls and personally placing them to be kicked, the opportunity for gaining personal perceptions of the ball would be standardized across the subjects. Following the kicking trials, each performer was asked four questions about the two balls during an exit interview (Appendix C). It should be noted, that although both balls were of a similar color, the weights and sizes were different. The Micro-Soccer ball was larger in circumference, but lighter than the standard youth soccer ball used in this study. When the children were asked: What ball did they "like" to kick best, 95% of the subjects chose the Micro-Soccer ball over the standard youth soccer ball. Of the 20 subjects, 65% of them thought the Micro-Soccer ball was "easier" to kick. The "hardest" ball to kick was the standard ball, chosen by 75% of the subjects. Ninety five percent of the subjects thought the Micro-Soccer ball was "more fun" to kick than the standard youth soccer ball. The specific results of the interview questions are provided in Table 23.

Table 23

Exit Interview Questions and Subject Selections

Question	Micro ("big")	Standard ("small")
1. Which of the two balls did you like to kick best, the big one or small one?	19	1
2. Which of the two balls was easier to kick, the big one or the small one?	13	7
3. Which of the two balls was harder to kick, the big one or the small one?	5	15
4. Which ball was more fun to kick, the big one or the small one?	19	1

Of interest to the investigator were the seven children who indicated the "small" ball was easier to kick and the five children who indicated the "big" ball was harder to kick. Listed in Table 24 is a summary of the stage levels and ages for the subjects who thought the small ball (standard youth soccer ball) was easier to kick: one at stage one, four years of age; two at stage two, three and four years of age; two at stage three, five and eight years of age; and two at stage four, five and eight years of age.

Table 24

Stage Level and Age of Subjects Who Thought the Standard Ball was Easier to Kick

	Stage 1	Stage 2	Stage 3	Stage 4
Number of subjects	1	2	2	2
Age (years)	4	3 and 4	5 and 8	5 and 8

Summarized in Table 25 are the subjects who thought the big ball (Micro-Soccer ball) was harder to kick: two at stage two, three and four years of age; two at stage three, five and eight years of age; and one at stage four, four years of age. Since developmental sequences are age related, but not age dependent, it may be possible that the children's perceptions followed a similar pattern. If that were true, the age related, not age dependent relationship may explain the responses of the children who indicated the "small" ball was easier to kick (even though it was heavier than the "big" ball) and the children who indicated the "big" ball was harder to kick (even though it was 26% lighter than the other ball). It is beyond the scope of this study, other than reporting the results of the exit interview to draw conclusions about this interview. It is suggested that consideration of equipment size may be of value in designing developmentally appropriate equipment.

Table 25

Stage Level and Age of Subjects Who Thought the Micro-Soccer Ball was Harder to Kick

	Stage 1	2	3	4
Number of subjects	*	2	2	1
Age (years)	*	3 and 4	5 and 8	4

Summary of results

This biomechanical study quantified angular displacements, velocities, and accelerations of the developmental sequence of kicking in children three to eight years of age at three specific points in the kick. These kinematic variables were compared to predicted trends of the developmental sequence of kicking using a direct approach as described by Haubenstricker, et al. (1981). Additionally, predicted trends were developed for the angled approach.

Children identified as stages one through four completed trials using a direct approach kicking a standard youth soccer ball and a newly developed light weight Micro-Soccer ball. Children identified as stages three and four also completed trials using an angled approach with both types of balls.

The first hypothesis tested was that the angular displacements, velocities and accelerations would follow the predicted trends, for both approach types, as defined for the preparatory, force production, and follow through phases. Most of the predicted trends during the direct approach with both the standard youth and Micro-Soccer balls were not supported in this study. The findings of this study related to the predicted trends are listed below.

At maximum backswing the stage one performers exhibited a neutral hip position at 180^0 when using the standard youth soccer ball. Stages two through four did not exhibit hip hyperextension as predicted with either ball type.

In all kicking trials, the predicted trend that the more skilled subjects (stage four) would exhibit a segmental relationship in which thigh rotation would dominate the force production phase when compared to shank rotation, was exhibited in the current study. Although, the segmental relationship described above, was observed in the stage three and stage four subjects, the stage four subjects had greater magnitudes of differences between the segmental rotations for the direct approach. The pattern observed in the stage three subjects was not predicted, however it could be considered an elementary form of the soccer paradox. The stage four subjects had a greater deceleration of the thigh than did the stage three subjects which illustrated their increased skill level. Contrary to the hypothesis tested, full knee extension at ball contact during a direct approach to the ball was not found. Although, it was predicted that progressive knee extension prior to and at ball contact would occur, the knee was flexed at ball contact in all cases for all stages with both ball types. More research is required with larger sample sizes, as well as high speed biomechanical video graphic analysis, to accurately assess the differences between the work by Haubenstricker et al. (1981) and the current study, with respect to knee angles at contact.

Knee extension continued during the follow through phase for all stages during the direct approach for both balls tested, as predicted. Additionally, the stage four subjects' results supported the predicted trend of an airborne phase during the follow through, as all of the stage four subjects were airborne, following contact during the direct approach for both balls tested.

Many of the predicted characteristics of the angled approach were evident in the current study. The predicted characteristic of the respective Basic and Mature Stage foot placement was found in this study, as the Mature Stage performers placed the foot of the support leg in the direction the ball was intended to be kicked, whereas the Basic Stage performers placed their foot along the approach line. The placement of the support foot is a characteristic that identified differences between skill levels during an angled approach. The Basic Stage performers exhibited an increase in angular velocities of both the thigh and the shank from maximum backswing to contact, which followed the predicted trend.

As in the direct approach, the soccer paradox, was found in the Basic and Mature Stage subjects' techniques. Additionally, the predicted trend of knee flexion at ball contact was supported by these data during an angled approach to the ball. Finally, knee flexion was maintained for the Basic Stage and Mature Stage subjects during the follow through phase, for the angled approach with both soccer balls, as predicted.

Balanced design ANOVA ($p < .10$) analyses were conducted to determine: (1) if differences existed in the rotations of the thigh, as well as the shank, of the kicking limb between subjects exhibiting stages three and four while using a standard youth soccer ball using a direct approach to the ball (hypothesis 2); (2) if differences existed in the rotations of the thigh, as well as the shank of the kicking limb of the subjects using a direct approach when compared with subjects using an angled approach, while kicking a standard youth soccer ball (hypothesis 3); and (3) if the resultant ball velocity of the light weight soccer ball will be greater than that of the standard youth soccer ball, regardless of approach (hypothesis 4).

The second hypothesis tested for differences in the rotations of the thigh, as well as the shank of the kicking limb between subjects exhibiting stages three and four while using a standard youth soccer ball using a direct approach. Significant differences were found at contact for both the angular velocity of the shank ($p = .017$), and angular acceleration of the thigh ($p = .003$). Additionally, angular velocity of the shank ($p = .024$) and angular velocity of the thigh ($p = .026$), were found significantly different at maximum forward movement (follow through). Since this hypothesis, in its entirety, was not shown significant, this hypothesis was rejected.

The third hypothesis of the current study tested if differences existed in the rotations of the thigh, as well as the shank of the kicking limb of the subjects using a direct approach when compared with subjects using an angled approach, while kicking a standard youth soccer ball. This hypothesis was rejected. Significant differences were found only for shank angular velocity at contact ($p = .043$). This hypothesis was developed as a result of the work by Isokawa and Lees (1988), who determined that kicking performance was significantly improved when using an angled approach of 45^0. A reason that may explain why the current hypothesis was rejected, was that the subjects were inexperienced in performing the angled approach, and therefore, were unable to capitalize on the greater range of motion provided by the angled approach with respect to pelvic rotation, and inward rotation, adduction and flexion of the hip.

The final hypothesis of the current study tested whether or not the resultant ball velocity of the light weight soccer ball would be greater than that of the standard youth soccer ball, regardless of approach. A significant difference ($p = .025$) between the standard youth soccer ball and the newly developed light weight soccer ball (Micro-Soccer ball) was found. However, there was not a significant difference between the type of approach used ($p = .503$), indicating that differences between the direct approach and the angled approach did not exist with respect to ball velocity. As indicated previously, the angled approach has been reported to increase kicking performance as measured by resultant ball velocity following contact (Isokawa and Lees, 1988). The results of the current study indicated that for this sample of subjects, the light weight ball had more of an effect on ball velocity, than did the approach used. Again, inexperience by the subjects using the angled approach may have been a factor in this finding.

The results of this study have identified specific kinematic variables of angular displacements, velocities, and accelerations associated with the developmental sequence of kicking in children, using direct and angled approaches to the ball. Insight into these parameters has been gained for the developmental sequence of kicking. The lack of significant differences between the kinematic variables between stages three and four, as well as between the direct and angled approach types indicated: 1) that experience of the subjects played a role; and 2) the two points of maximum backswing and maximum forward movement may not discriminate within the skill of kicking.

Biomechanical study of the characteristics of kicking is an effective manner to continue developing methods and techniques for teaching and coaching. The results of the current study did find differences which may modify the findings of Seefeldt and Haubenstricker (1972) and Haubenstricker, et al. (1981). Quantifying the kinematic variables of angular displacements, velocities, and accelerations can supplement visual assessment of the kicking skill. Finally, the effects of a light weight ball were evident for this sample of children, regardless of the approach that was used, as the children were able to kick the Micro-Soccer ball with a greater velocity than the standard youth size three soccer ball.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Investigating the quantitative aspects of the development of kicking is important to an increased understanding of kicking for the purposes of improving teaching and coaching techniques and the skill development of children. Therefore, the purposes of this study were: (a) to identify selected kinematic variables associated with children exhibiting stages one through four while kicking a standard youth soccer ball and a newly developed light weight soccer ball (Micro-Soccer ball) using direct and angled approaches to the ball; (b) to identify the differences in selected kinematic variables associated with children exhibiting kicking stages three and four using a direct and angled approach to the ball while kicking a standard youth soccer ball; and (c) to determine if there were differences in the resultant ball velocity of a standard youth soccer ball versus a lightweight soccer ball, when kicked by subjects exhibiting stages three and four, for both the direct and angled approaches.

The kinematic variables of angular displacements, velocities and accelerations for the skill of kicking were determined for 20 children who ranged in age from three to eight years of age. Subjects selected for participation in this study were classic examples of one of the four developmental stages of kicking as outlined by Seefeldt and Haubenstricker (1972). The children were assigned to developmental groups as follows:

two subjects each at stages one and two, and eight subjects each at stages three and four. All of the subjects completed trials using the direct approach kicking a standard youth soccer ball and the Micro-Soccer ball. The stage three and four subjects completed additional trials using an angled approach kicking both ball types. Subject trials were recorded using standard three-dimensional biomechanical videographic methods. Subsequent calculations and smoothing of data were obtained from the Aerial Performance Analysis System (APAS) modules for analysis.

Predicted trends were tested for each stage during the direct approach and Basic and Mature Stages for the angled approach. The selected kinematic variables of angular displacements, velocities, and accelerations were obtained at maximum backswing of the kicking leg (preparatory phase), contact (contact portion of the force production phase), and maximum height of the kicking foot after the ball left the foot (follow through phase).

The first hypothesis, that the selected kinematic variables of angular displacements, velocities, and accelerations would follow the predicted trends as stated for the direct and angled approaches was rejected. Listed in Table 26 were the characteristics found for the direct approach for both ball types. An overview of the preparatory phase (maximum backswing), the force production phase (foot/ball contact), and the follow through phase (maximum forward movement) is found in Table 26. The changes in joint positions and kinematic variables listed in Table 26 were referenced from the previous less skilled stage. Joint angles in the table are provided for use by the practitioner when working with students or athletes.

Table 26

Characteristics found for the Direct Approach with a Standard Youth/Micro-Soccer Ball

Stage 1	Stage 2	Stage 3	Stage 4
	PREPARATORY PHASE		
		Step	Leap
No hip hyperext. 180°/162°	Hip flexion 171°/174° Knee flexion 161°/ **extension 172°**	<Hip flexion 177°/175° >Knee flexion 135°/128°	>Hip flexion 174°/168° >Knee ext. 142°/139°
	FORCE PRODUCTION PHASE		
	Shank Angular	Shank Angular	Shank Angular
	$<\theta$ / $<\theta$ $>\omega$ / $>\omega$ $>\alpha$ / $>\alpha$	$<\theta$ / $<\theta$ $>\omega$ / $>\omega$ $>\alpha$ / $>\alpha$	$>\theta$ / $>\theta$ $>\omega$ / $>\omega$ $>\alpha$ / $>\alpha$
	Thigh Angular	Thigh Angular	Thigh Angular
	$<\theta$ / $<\theta$ $>\omega$ / $>\omega$ $<\alpha$ / $>\alpha$	$>\theta$ / $>\theta$ $>\omega$ / $<\omega$ $<\alpha$ / $<\alpha$	$>\theta$ / $>\theta$ $<\omega$ / $<\omega$ $<\alpha$ / $<\alpha$
No parallel thigh Knee flexion 127°/131° Hip flexion 155°/150°	>Knee flexion 112°/108° *>Hip ext. 162°/154°*	>Knee flexion 89°/95° *>Hip flexion 154°/152°* *Elem. Soccer Paradox*	>Knee flexion 89°/95° *>Hip flexion 150°/145°* Soccer Paradox
	FOLLOW THROUGH PHASE		
Knee hyperextension 189°/**flexion 177°**	Knee hyperextension 181°/186°	Knee flexion 175°/179°	Complete knee ext. 180°/ **knee flexion 175°** Airborne

θ = Angular displacement
ω = Angular velocity
α = Angular acceleration

Bold = Difference between ball types
Italic = Additional findings

Predicted characteristics found during the preparatory phase of the direct approach using a standard youth soccer ball and a Micro-Soccer ball are presented in Table 26. Each of the stage four subjects used a leap on the final step of the approach. As predicted, hip hyperextension was not found for the stage one subjects using either ball type. Rather than hip hyperextension for stages two through four as predicted, slight hip flexion was found at maximum backswing for both ball types, with the exception of stage one subjects who exhibited a hip joint angle of 180^0 while kicking the standard ball. Knee flexion was found at maximum backswing across all four stages with both ball types, and (knee flexion) did not progressively increase as predicted.

At contact of the direct approach few of the predicted characteristics were found. Mean shank angular velocity and acceleration were found to progressively increase from stage one to stage four with both ball types. Also, mean thigh acceleration progressively decreased across all four stages using the standard ball. As predicted, the stage four subjects exhibited segmental rotations which were characterized as the soccer paradox. The segmental rotations found in the stage four subjects coincided with the segmental rotations discussed by Glassow and Mortimer (1968) and Putnam (1993). The mean shank angular acceleration at contact was at 8355 deg/sec^2 (7900 deg/sec^2, Micro-Soccer ball) and the mean thigh angular acceleration was -6698 deg/sec^2 (-8044 deg/sec^2, Micro-Soccer ball), which indicated the presence of the soccer paradox for both ball types. Although not predicted, the stage three subjects exhibited a similar pattern of the rotations for the shank and thigh for both ball types, which was characterized as an elementary form of the soccer paradox. The stage three subjects did not have as great a difference in magnitude between the rotations of the shank and the thigh as the stage four subjects. The greater difference in magnitude between the rotations of the thigh and shank illustrated the stage four subjects' higher skill level when compared to the stage three subjects. An additional finding not predicted was that knee flexion at contact progressively increased from stage one to stage four for both ball types. This finding of a flexed knee at contact, is in sharp contrast with the descriptions of the developmental sequence of kicking as discussed by Haubenstricker et al. (1981). Knee flexion at contact is a characteristic that is taught by many soccer coaches and is taught to coaches at coaching academies. Finally, hip flexion was found at contact for all four stages with both ball types.

During the follow through of the direct approach, as predicted, all of the stage four subjects were airborne. Although being airborne is not the only criterion for a stage four subject, it did indicate that the stage four subjects produced sufficient momentum during the kick in order to become airborne. Production of sufficient momentum during the kick, resulting in the body becoming airborne is a characteristic that illustrated greater skill level in a performer.

Few differences were found when comparisons were made between the standard youth soccer ball and the Micro-Soccer ball using a direct approach with respect to the predicted characteristics. The Micro-Soccer ball was not found to have an effect on the angular displacements, velocities, and accelerations as previously predicted. During the preparatory phase, the stage one subjects exhibited a greater backswing with the standard ball than with the Micro-Soccer ball, indicated by a hip joint angle difference of 18^0. Additionally, during the preparatory phase, the stage two subjects' knee flexion while kicking the standard soccer ball was 11^0 less than the knee joint angle while kicking the

Micro-Soccer ball. At contact, a decrease was found in thigh angular velocity for the stage three subjects with the Micro-Soccer ball, whereas an increase was found with the standard ball. Also at contact, mean thigh angular deceleration was not as great while subjects kicked the Micro-Soccer ball compared with the deceleration while kicking the standard ball. During the follow through, minimal differences were exhibited in the knee and hip joint angles.

Research is prevalent using adult subjects in the study of kicking. However, to date no literature was found on the developmental sequence of an angled approach to the ball in children. Subjects identified at stages three and four were used in this study to evaluate the predicted trends of the angled approach. Predicted trends were established for the Basic Stage (stage three) and the Mature Stage (stage four) using both the standard youth soccer ball and the newly developed Micro-Soccer ball.

A number of the predicted trends for the angled approach using a standard youth soccer ball and Micro-Soccer ball were supported (Table 27). During the preparatory phase with both ball types, the Basic Stage performers placed their non-kicking support foot along the angled approach line, in contrast with the Mature Stage performer's foot placement which was along the intended path the ball was to be kicked. The Mature Stage subjects' support foot placement reinforced the thought by the current study's investigator, that a more mature kicking technique was required to perform an angled approach at a high level of skill.

Table 27

Characteristics Found for an Angled Approach Using a Standard Youth/Micro-Soccer Ball

Basic Stage	Mature Stage
PREPARATORY PHASE	
Step	Leap
Support foot along approach path	Support foot parallel to intended direction of ball travel
Hip flexion $175^\circ/172^\circ$	>Hip flexion $169^\circ/171^\circ$
Knee flexion $135^\circ/130^\circ$	>Knee extension $144^\circ/141^\circ$
FORCE PRODUCTION PHASE	
Increasing thigh and shank velocity	Soccer paradox
Hip flexion $153^\circ/150^\circ$	*>Hip flexion 150°/>extension 152°*
Knee flexion $100^\circ/94^\circ$	>Knee flexion 97°/>*extension 100°*
Elementary Soccer Paradox	
FOLLOW THROUGH PHASE	
Knee flexion $177^\circ/175^\circ$	>Knee flexion $176^\circ/176^\circ$
Hip flexion $138^\circ/138^\circ$	>Hip flexion $128^\circ/128^\circ$

Italic = Additional findings

The Mature Stage performers' technique enabled them to use the additional actions of inward rotation and adduction of the support leg hip as a result of the positioning of the non-kicking leg. This not only increased the number of muscle groups involved, but also increased the range of motion through which the leg moved, thereby enabling the segments to reach higher velocities prior to ball contact. Also as predicted, knee flexion at maximum backswing (preparatory phase) was found to be greater for the Mature Stage subjects than for the Basic Stage subjects (Table 27). The greater knee flexion exhibited by the Mature Stage subjects resulted in a shortened moment arm, allowing the subjects to swing the leg through quickly, reaching greater kicking limb velocities.

At contact with the standard ball, mean knee joint angles were found to be 100^0 for the Basic Stage and 97^0 for the Mature Stage subjects with the standard ball. With the Micro-Soccer ball, the Basic Stage subjects exhibited a 94^0 knee joint angle, while the Mature Stage subjects exhibited a 100^0 knee joint angle at contact. Although the knee was in a more extended position for the Mature Stage subjects in comparison to the Basic Stage subjects, the knee was still in a flexed position. These findings supported the predicted characteristics of knee flexion at contact. Additionally for both ball types, hip flexion was found in the Basic Stage subjects as predicted, with greater hip flexion found for the Mature Stage performers. As predicted for the Basic Stage performers, shank and thigh angular velocities were found to have increased from maximum backswing to contact for both ball types.

As found in the direct approach (stage four), the soccer paradox relationship was found for the Mature Stage subjects during the angled approach with both ball types. The relative angular accelerations found in the Mature Stage subjects' thigh and shank highlighted the difference between the Basic and Mature Stage subjects with respect to coordination and technique used during an angled approach.

During the follow through phase of the angled approach, knee flexion was predicted to be maintained as hip flexion occurred for both the Basic and Mature Stage subjects. Knee flexion was found to be maintained at maximum forward movement of the kicking foot for the Basic Stage subjects and for the Mature Stage subjects with minimal differences between ball types (Table 27). Hip flexion was also found in the follow through phase, with the Mature Stage subjects' hip flexion greater than the Basic Stage subjects, with no difference between ball types. The difference in hip flexion between the two stages was explained as a result of increased segmental velocities by the Mature Stage subjects. The increased segmental velocities resulted in increased momentum of the leg segments, thereby causing increased hip flexion during the follow through. The greater momentum was substantiated by the resultant ball velocity at contact.

Most of the predicted trends were found for the angled approach using both the standard youth soccer ball and the Micro-Soccer ball, with minimal differences between ball types. A finding not predicted, that was found for both approaches and both ball types was that of an elementary form of the soccer paradox in the stage three subjects. The magnitude of differences of the rotations of the thigh and shank were not as great for the Basic Stage (stage three) subjects as for the Mature Stage (stage four) subjects. However, as skill level increased across stages, there was a greater deceleration of the thigh, relative to the acceleration of the shank at contact. The rotations of the thigh relative to the shank appear to be characteristic differences between skill levels. Although, a coach or a teacher should not teach a performer to stop the thigh purposely, as a performer's skill level increased it should be possible to visually observe what appears to be a slowing or a stopping of the thigh as the shank moves to contact. The information on the movement of the thigh and the shank should help the practitioner in evaluating levels of kicking skill.

The second hypothesis tested, which investigated significant differences in the rotations of the thigh, as well as the shank, of the kicking limb between subjects exhibiting stages three and four while using a standard youth soccer ball was rejected in this study. Although rejected as a whole, several differences were found significant at contact and maximum forward movement. The lack of measurable significance at maximum backswing for this study may be explained by the point chosen for analysis. If the point selected were truly maximum backswing, the movement of the kicking leg would have stopped or there would be minimal movement prior to beginning its forward swing, regardless of the stage.

Significant differences for the stage three and four subjects in angular velocity of the shank ($p = .017$) and the angular acceleration of the thigh ($p = .003$) were found at contact. The stage four subjects were found to have a greater shank angular velocity and a greater thigh deceleration. The significant differences found in the angular velocity of the shank as well as the angular acceleration of the thigh may have indicated that the stage four subjects were better able to utilize the segmental relationships in performing the kick. Also, the stage four subjects' shank angular velocity may have been significantly greater because they were able to capitalize on the movement of the thigh.

At maximum forward movement of the kicking foot, a significant difference was found for the angular velocity of the shank ($p = .024$) and the angular acceleration of the thigh ($p = .026$). The significant differences found in the angular velocity of the shank and the angular acceleration of the thigh may have been a result of a reduction in the relative moment arm of the kicking leg for the stage four subjects while airborne. Modification of the relative moment arm length would be required for the purpose of balance and timing. Examining the moment arm length relative to balance of the body was outside the scope of the current study.

Even though the second hypothesis was rejected as stated, observable differences also were found in the graphs of angular velocity of the thigh and shank for randomly selected stage three and four subjects. It appeared that there was a difference in the timing and coordination of the leg segments between the stage three and four subjects with respect to angular velocities of the thigh and shank. Although a coach or teacher may attempt to encourage a participant to maximize velocity of the kicking limb segments, timing and coordination of the kicking sequence must be emphasized for children regardless of the stage level to develop correct kicking technique.

The third hypothesis of this study stated that there would be significant differences in the rotations of the thigh, as well as the shank, between a direct approach and an angled approach using a standard youth soccer ball. This hypothesis was rejected. As discussed earlier, the angled approach has been attributed to increased kicking performance by adults. The only significant difference found was that of the angular acceleration of the shank at contact ($p = .043$). The significant difference between the approaches with respect to the angular acceleration of the shank was likely due to the increased difficulty of the angled approach over the direct approach and the inexperience of the subjects performing this task. Overall, the angular acceleration of the shank was lower for the angled approach when compared to the direct approach. A lack of experience with an angled approach may have caused the children to concentrate more on the task of completing the approach, rather than executing a maximal effort kick. The foot placement of the stage four subjects indicated that other variables, such as timing and technique, could contribute to performance of the angled approach (Mclean & Tumilty, 1993). Finally, all the changes in movement which occur during the kick may not have been captured by the video tape due to the relatively low frame rate of the cameras. Intricate changes in human movement are difficult, if not impossible, to capture without high frame rates.

The final hypothesis of this study stated that the resultant velocity of the lightweight ball (Micro-Soccer ball) would be greater than that of the standard youth soccer ball regardless of the approach. For both approaches, resultant ball velocities were significantly different between the Micro-Soccer ball and the standard youth size three soccer ball ($p = .025$). The mean initial velocities (V_o) of the standard ball during the direct approach were 7.46 m/sec and 11.66 m/sec for stages three and four, respectively. In comparison, the mean initial velocities of the Micro-Soccer ball using the direct approach were 9.03 m/sec and 14.24 m/sec for stages three and four, respectively. The mean initial velocities of the standard ball during the angled approach were 8.26 m/sec for the Basic Stage and 10.45 m/sec for the Mature Stage. Finally, the initial velocities for the Micro-Soccer ball using an angled approach were found to be 8.90 m/sec for the Basic Stage and 12.62 m/sec for the Mature Stage. The lightweight ball did have an effect on ball velocity, with the Micro-Soccer ball having a greater resultant velocity than the standard youth soccer ball for both approaches. However, the lightweight Micro-Soccer ball was not shown to be a significant factor in ball velocity between the direct and angled approaches in the current study ($p. = .503$). It is likely that a lack of experience of the children completing an angled approach, caused the children to concentrate more on the task of completing the approach which may have resulted in a less than maximum ball velocity for the angled approach.

Not only did the subjects kick the Micro-Soccer ball with greater velocity, they appeared to enjoy kicking the ball more. Through an exit interview, 95% of the subjects liked to kick the Micro-Soccer ball the best, 65% thought it was easier to kick, 75% thought the standard youth ball was harder to kick, and 95% thought the Micro-Soccer ball was more fun to kick. The Micro-Soccer ball was slightly larger in circumference than the standard youth ball, and 26% lighter.

Several issues arose as a result of the limited number of the predicted trends being supported as well as in the findings of the lack of significance in the hypotheses of this study. The hyperextended position of the hip at maximum backswing, defined by some researchers, may be due to one of or both of the following: 1) a misperception of the trunk position relative to the thigh, and 2) lumbar hyperextension. If the trunk were inclined anteriorly at maximum backswing of the kicking leg, hip hyperextension may appear to be present. However, if the inclination of the trunk is examined relative to the thigh, hip hyperextension may not exist. Additionally, if the pelvis rotates anteriorly, hip hyperextension may also be perceived by the observer. Relative to the pelvis however, no hip hyperextension exists. These misperceptions may result in inaccurate visual assessments of hip positions relative to the trunk. Although this study did not address trunk inclination angle, differences between the stages with respect to trunk inclination at maximum backswing, contact, and maximum forward movement were observed on the video tapes of the subjects.

Another issue was that of the selection of the specific points at maximum backswing and maximum forward movement. The selection of these specific points may have resulted in a lack of significant differences because of the limited movement of the segments at these points in time. The potential of missing real differences may have occurred as a result of the video film speed and the data reduction process. It may have been more appropriate to select numerous points along the path of the kick in order to represent the full sequence to determine if significant differences existed. However, these points were selected based on the work by Haubenstricker et al. (1981)

Additionally, the qualitative characteristics developed by Seefeldt and Haubenstricker (1972) and subsequently validated by Haubenstricker et al. (1981) distinguished points along a continuum of kicking. Other variables, such as balance or interactions of other body segments may have contributed to the identification of kicking skill level and subsequent significant differences.

The results of the current study will add to the foundation of the developmental sequence of kicking using the direct approach. The current study also laid a foundation with respect to the developmental sequence of kicking using an angled approach. Additionally, it has been shown that a lightweight ball can improve kicking performance, as measured by resultant ball velocity. Finally, coaches and teachers will be able to use this information to improve kicking skill in children.

Recommendations

1. Future studies should consider studying subjects beyond the three to eight year old range of the current study. Samples of subjects of different ages would provide greater input into the development of kicking. Additionally, comparisons between "mature" level stage four children could be compared to "elite" soccer players, such as those in the

Olympic Development Program, or on select travel teams. Even though the magnitudes of the selected kinematic variables would be markedly different, the patterns observed could be compared.

2. Future studies should consider the use of only soccer experienced children, non-soccer experienced children, or a comparison of the two classifications to examine the development of kicking in children.

3. Future studies should consider longitudinal studies of children to examine developmental changes.

4. Future studies should consider the interactions of the thigh, shank and foot. Studying the interaction between these segments would enable the investigator to determine the contributions of the selected segments. Skill level comparisons could be conducted to differentiate between skill levels.

5. Future studies should consider the development of a targeting solution of the pelvis and trunk to determine their relative positions during a kick. This would further aid in the accurate description of a kick.

6. Kinetic variables should be considered. Force platform data would add to the current study's examination of the development of kicking in children. For example, ground reaction forces could be compared between skill levels to further differentiate between skill levels.

7. Future studies should consider the use of high speed cameras to study the development of kicking. High speed cameras, integrated with automated motion analysis systems would enable the researcher to identify variables, otherwise unobservable, as a result of inadequate camera speed. Because of the ballistic nature of the skill of kicking,

an increased number of data points could be collected with high speed cameras in order to more intricately analyze the skill of kicking.

8. Future studies should consider the use of automated motion analysis systems in order to video tape an increased number of subjects and increase the number of identified landmarks. The investigator would be able to increase statistical power by increasing the sample size, as well as identify patterns of motion of other body segments.

9. Future studies should investigate the scaling of equipment to children. Different weights and sizes of soccer balls are known to affect kicking performance as measured by resultant ball velocity.

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APPENDIX A

APPENDIX A

WRITTEN INFORMED CONSENT
FOR
A kinematic analysis of the developmental sequence of kicking using a direct and angled approach
Michigan State University
Department of Physical Education and Exercise Science

1. I have freely consented to take part in a scientific study investigating the kinematic variables associated with the developmental sequence of kicking by Alfred H. Bransdorfer under the direction of Dr. Dianne Ulibarri.

2. I understand that to perform this analysis the following measurements will be taken:

   a. I will be video taped as I kick two balls, each three (3) times using a direct and angled approach to the ball (12 kicks plus 2 extra for miss kicks). Note: Stage one and two subjects will use only a direct approach and complete six kicks.

   b. I will be involved in one filming session lasting approximately 45 minutes.

   c. I will have small reflective balls attached with double sided hypo-allergenic tape to my shoe, ankle, knee, shin, and hip to aid in determination of those locations during the analysis phase of the study.

   d. I will have the lengths and heights of specific limbs measured as well as my body weight.

3. I understand that if I am injured as a result of my participation in this research project, Michigan State University will provide emergency medical care if necessary. I further understand that if the injury is not caused by the negligence of MSU I am personally responsible for the expense of this emergency care and any other medical expenses incurred as a result of this injury.

4. I understand that I am free to discontinue my participation in the study at any time without penalty and will in no manner effect my future relationship with Michigan State University.

5. I understand that the participation in this study is strictly voluntary and will not involve payment.

6. I understand that data from my performances may be used for demonstrations, instruction, and study.

7. I understand that my name will not be used in any publication, presentation, or discussion of data based upon my performances.

8. I understand that the video taped recording of my trials, that could identify me will not be used in any publication, presentation or discussion without my expressed written consent.

9. I understand I will receive a copy of my individual results, and that I can receive additional information about this study or these results after my participation is completed.

Date: __________

Parent/Guardian Signature ______________________________

Minor Assent ( ) Yes ( ) No

Address ____

____

____

Phone Number ________________________________

APPENDIX B

APPENDIX B

SUBJECT INFORMATION AND ANTHROPOMETRY

A KINEMATIC ANALYSIS OF THE DEVELOPMENTAL SEQUENCE OF KICKING USING A DIRECT AND ANGLED APPROACH

Date __________ **Subject # ________**

Name ____

Address ____

City ____________________State ___________________

Zip __________________

Phone Number (____)_____________________________

Date of Birth ____________________________________

Measurements

Height ___________________ Weight _______________

Right Leg

Thigh (Greater trochanter of femur to lateral epicondyle) _________

Shank (Lateral condyle of tibia to lateral malleolus) _________

Foot (Lateral malleolus to distal end of 5th metatarsal) _________

Leg height (Greater trochanter to floor) _________

Shank height with foot (Lateral condyle of tibia to floor) _________

Notes:

APPENDIX C

APPENDIX C

EXIT INTERVIEW
FOR
A KINEMATIC ANALYSIS OF THE DEVELOPMENTAL SEQUENCE OF KICKING
USING A DIRECT AND INDIRECT APPROACH

Subject # ___________

Directions: Please read each question to the subject and **circle their response**. The subject's parents may need to help assist the child in answering.

1. Which of the two balls did you like to kick best, the big one or small one?

2. Which of the two balls was easier to kick, the big one or the small one?

3. Which of the two balls was harder to kick, the big one or the small one?

4. Which ball was more fun to kick, the big one or the small one?