BIOMECHANICAL ANALYSIS OF INSTEP KICK IN SOCCER

By

SUBHASH BASUMATARY

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Department of Human Movement, Recreation and Performance,
Melbourne, Australia

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STATEMENT OF RESPONSIBILITY

I hereby certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgements and that neither the thesis or the original work contained therein has been submitted to this or any other institution for a higher degree.

[redacted]

Subhash Basumatary
Victoria University
Melbourne, Australia
December, 1998

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ABSTRACT

Author: S. Basumatary
Institution: Victoria University
Date: December, 1998

The game of soccer involves complex motor actions of the human body. Among the various kicking motion performed by the soccer players, the instep-kick occupies a place of fundamental importance. The player exhibits different levels of speed and trajectories of the ball by controlling the kinematic variables, the dynamics and motor co-ordination of various joints and body segments, especially of the lower limbs. To date there have been limited research undertaken investigating the effects of approach angles on the three dimensional kinematics of instep-kick in soccer. The research presented in this thesis investigated the effect of approach angle variations on distance covered by the ball, accuracy of the kick and 3D human body kinematics during soccer instep-kicks.

Twenty male soccer players from the State Soccer League of Victoria volunteered to participate in the study. The subjects' kicking motion were recorded and analysed using a PEAK 3D-motion analysis system. Two synchronised Panasonic F-15, 50-Hz video camera placed 90° apart recorded the kicking motion of the subjects for seven approach angles (0, 15, 30, 45, 60, 75 and 90 degrees). Nineteen anatomical locations on the human body, position of two cones and the ball centre were manually digitised for each camera view and also for each of the approach angles. The 2D coordinates were smoothed using a low pass Butterworth digital filter and the

smoothed coordinates were used to reconstruct their 3D spatial positions (X, Y, Z) using the PEAK system's Direct Linear Transformation (DLT) algorithm. A number of body-kinematic variables were extracted from the 3D positional data, including linear velocities of the hip, knee, ankle, heel, toe and centre of mass of the body along the direction of target, and also angular velocities hip, knee and ankle joints.

The effect of approach angles on maximum distance covered by the ball, accuracy of the kick (deviation from the target axis), ball velocity at 'take-off' and human body kinematics was determined using *Two Way Analysis of Variance* (ANOVA) statistical techniques. A Bonferroni *post-hoc* test was applied in cases where "F" ratios were significant, to find out which of the differences of the paired means were significant. For testing the hypothesis, the level of confidence was set at 0.05. Standard *Multiple Regression Analysis Technique* at the 0.05 level of significance was applied in order to fit a relationship between the dependent variables and approach angles. The effect of body kinematic variables and ball velocities on maximum distance travelled by the ball at different approach angles were determined by *stepwise regression equation.*

Analyses of data revealed that there was a significant effect of approach angles on distance covered by the ball ($p< 0.0001$) and also accuracy of the soccer kick ($p<0.0001$). Both the maximum distance covered by the ball ($x = 39.01$ m) and the highest accuracy ($x=0.92$ m) were found to be for an approach angle of 45°. Approach angles also significantly affected linear velocities of hip ($p<0.0001$), knee ($p<0.0001$), heel ($p<0.045$), toe ($p<0.0001$), body centre of mass ($p<0.0001$), ball ($p<0.0001$) and angular velocities of the knee ($p<0.001$) and ankle ($p<0.048$). Stepwise regression analysis suggested that the toe linear velocity ($p<0.027$) and the hip ($p< 0.002$) and knee ($p<0.006$) angular velocities at ball contact were significant contributors to the cause of distance travelled by the ball ($p<0\ 0.006$).

The results of the investigation suggest that approach angles play important role while instep-kicks are performed. The approach angles of 30° to 60° were found to yield both maximum distance and also very good accuracy of the instep kick, with the maximum distance and highest accuracy being at 45°. Approach angles in the range 30° - 60° also yielded maximum linear velocity of the ball at 'ball take-off'.

It appears from an investigation into the body kinematic data that approach angles can significantly affect a number of body dynamic velocities at ball contact including the body centre of mass. Linear velocity of body centre of mass remained fairly constant up to 45° approach angle, following that it decreased abruptly suggesting a reduction in linear momentum of the body along the direction of kick for approach angles > 45°.

Linear velocity of the toe was found to be a significant contributor to the cause of distance covered by the ball for all approach angles, however toe velocity was also dependent on approach angles. Angular velocity of the hip and knee both significantly contributed to the cause of distance covered by the ball. Modelling results suggest that the predicted distance covered by the ball increases fairly linearly with hip angular velocity when knee angular velocity is small, while the distance travelled by the ball remains invariant with hip velocity when knee velocity is large.

The results of the investigation suggest that instep-kick involves complex movement of the whole body specially the lower extremity and requires a 3D representation of its motion for complete analysis. Further research may be focused on kinetic and electromyographic analyses, gender differences, various age groups and different skill levels.

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Chapter i

INTRODUCTION

The game of soccer is intrinsically attractive to millions of people worldwide. It provides immense enjoyment to those playing or watching the game. Events such as the World Cup elevate human emotions and curiosities in a manner that almost defies logic. Approaching and analysing soccer phenomena in an objective manner pose no mean challenge to both professionals in soccer business and to sports science researchers (Reilly et al., 1993).

The game of soccer requires many skills, which are commonly taught at various levels of training programs; but skill levels have been quite difficult to evaluate. Soccer includes many skills such as *positional play, feints* and *pivots, running, dribbling, passing* and *kicking* which are frequently performed by the soccer players during the game. In a true sense one can state that soccer is a game with a complex system of motor actions (Burdan, 1955).

When examining the complex system of motor actions used in the game of soccer, the instep-kick obviously occupies a place of fundamental importance. The player tries to exhibit different levels of speed and trajectories of the ball, all with high level of precision in the execution of this skill. The only way to reach these chosen objectives is by controlling the kinematic variables, the dynamics and motor co-ordination of various joints and body segments, especially of the lower limbs (Rodano and Tavana, 1993).

According to soccer Coaches, the soccer instep kick is more likely to result in maximum ball velocity and in greater accuracy compared to "toe-kick", "inside-kick" or "outside-kick". It is the type of kick in which the ball is contacted with the instep (over the shoelace) of the kicking foot and is especially advantageous in scoring, free kicking and passing situations (Heyward, 1971).

Many researchers dedicated their time to study the complex kicking motion of soccer by examining the relevant biomechanical variables. These include kinematic studies concerning the importance of non-kicking leg position and knee joint angles (Burdan, 1955; Togari, 1972) and also the orientation and angular displacements of the kicking leg and foot at ball contact (Aitchison and Lees (1983) or before ball contact (Roberts and Metcalfe, 1968; Copper et al., 1982) for successful kicking. Studies also elicited that there is relationship between the swing velocity of the kicking limb, striking mass at impact and the ball velocity (Plagenhoef, 1971). Kicking is governed by the motor characteristics of individual player (Rodano and Tavana, 1993) and different level of players have a different swing motion kinematics (Togari, 1972). There seems also to be a general developmental trend, which most children tend to follow when learning a motor skill (Bloomfield et al., 1979). A few investigation on the influence of approach angle on ball velocity confirmed that angled approach produces greater ball velocity compared to a straight approach to the ball (Plagenhoef, 1971; Asai et al., 1980). Isokawa and Lees (1988) were the first to investigate the relative influence of approach angle (0°, 15°, 30°, 45°, 60° and 90°) on ball velocity and demonstrated that approach angles between 30° to 60° generated maximum ball velocity. It appears that no research has been undertaken on the effect of the approach angle on distance and accuracy of the instep kick. Also very little is known about the effect of approach angles on human body kinematics at the important event of ball contact. This study was undertaken to, provide a three-dimensional analysis of the kinematic variables that play a major role in the instep kick in soccer.

1.1 STATEMENT OF THE PROBLEM

The main purpose of the study was to investigate the kinematics of instep kick in soccer and to determine the effect of approach angle variations on distance covered by the ball and accuracy of the kick.

Specifically, the research project examined the relationship among the various kinematic variables (e.g. linear and angular velocities of lower limb joints and segments, etc.), maximum distance covered by ball and accuracy of the instep kick taken at different approach angles.

1.2 SIGNIFICANCE OF THE STUDY

The performance level of soccer players as observed in various tournaments and competitions are improving day by day. The principal factors for this improvement is the development of new training methods based on the scientific principles derived from various fields of sports sciences, which are incorporated in all levels (Beginners, Intermediate and Advanced) of soccer training.

For the reason stated above, the results of this study should be of vital importance in the following ways:

- The results of the investigation examine the relationship, if any, among the approach angles, distance covered by the ball and accuracy of the instep kick in soccer.
- It should be of considerable help to the coaches and physical education teachers to understand the correct technique of the instep kick in order to impart improved training to their pupils.
- Since high drive with precise accuracy plays an important role in soccer game, thus the finding of this study may also be helpful in the selection of best possible team.
- The findings of this 3-D biomechanical investigation should add to the body of knowledge in the area of biomechanics of soccer.

1.3 DEFINITION AND EXPLANATION OF TERMS

Angular Velocity: The rate of change of angular displacement with respect to time is known as angular velocity (deg/s).

Ball Contact: The first instant of time when the kicking-foot contacts the ball.

Ball Take-off: The first instant of time when the ball leaves the foot following the contact.

Camera Axis: An imaginary line that is orthogonal to the film plane of the camera and passes through a point in which the principal ray enters the lens (Miller and Nelson, 1973).

Coefficient: A known numerical quantity used to explain or modify a variable.

Digital Filter: A frequency selective device that accepts as input a sequence of equispaced numbers Y (t), and operates on them to produce as output another number sequence, Y (t), of limited frequency (Wood, 1982).

DLT: Known as Direct Linear Transformation. A technique for reconstruction of three-dimensional (3D) motion that involves converting two-dimensional co-ordinates obtained from two cameras into three-dimensional spatial co-ordinates by a set of transformation equations (Shapiro, 1978).

Frame Rate: The frequency with which cinematographical cameras record images (Miller and Nelson, 1973).

Hypothesis: A prediction or assumption that can be tested to determine whether or not it is correct.

Instep kick: A style of soccer kick in which the dorsal surface of the foot strikes the ball. The foot segment is extended upon impact and effected in the saggital plane by forceful hip flexion and knee extension.

Kinematics: It is the study of motion without any reference to force, i.e. time, distance, displacement, velocity and acceleration. Linear kinematics deals with translation or linear movement and angular kinematics explains rotatory or angular movement.

Kinetics: A description of motion that includes consideration of force as the cause of motion.

Linear Velocity: The rate of change of an object's position with respect to time is known as linear velocity (m/s).

Take-Board: A device for securing subject and trial numbers in view of each camera.

1.4 ABBRIVIATIONS AND SYMBOLS

AA	Approach angle
AAV	Angular velocity of ankle
ANOVA	Analysis of variance
BBC	Before ball contact
BC	Ball contac
DCB	Distance covered by the ball
BTO	Ball take-off
COM	Centre of mass
deg/s	Degree per second
HAV	Angular velocity of hip
KAV	Angular velocity of knee
LVA	Linear velocity of ankle
LVB	Linear velocity of ball
LVH	Linear velocity of hip
LVHE	Linear velocity of heel
LVK	Linear velocity of knee
m/s	Metre per second
ε	Error

1.5 HYPOTHESES

The following null hypotheses were tested at the .05 level of significance.

1. There is no significant effect of approach angles on distance covered by the ball.
2. There is no significant effect of approach angles on an accuracy of the kick.
3. There is no significant effect of approach angles on the linear velocity of the hip at ball contact.
4. There is no significant effect of approach angles on the linear velocity of the knee at ball contact.
5. There is no significant effect of approach angles on the linear velocity of the ankle at ball contact.
6. There is no significant effect of approach angles on the linear velocity of the heel at ball contact.
7. There is no significant effect of approach angles on the linear velocity of the toe at ball contact.
8. There is no significant effect of approach angles on the linear velocity of the centre of mass of whole body at ball contact.
9. There is no significant effect of approach angles on the linear velocity of the ball at ball take-off.
10. There is no significant effect of approach angles on the angular velocity of the hip joint at ball contact.
11. There is no significant effect of approach angles on the angular velocity of knee joint at ball contact.

12. There is no significant effect of approach angles on the angular velocity of ankle joint at ball contact.

13. There is no significant effect of linear velocity of lower limb joint and segments at ball contact on distance covered by the ball.

14. There is no significant effect of angular velocity of the hip, knee and ankle at ball contact on distance covered by the ball.

1.6 DELIMITATION

The study was delimited to: -

1. Twenty division IV male soccer players of state league Victoria between the age group of 20 - 30 years.
2. Kinematic investigation of hip, knee, ankle, heel, toe, centre of mass of the whole body and ball.
3. The maximum distance of instep kick with accuracy.
4. The approach angles of 0°, 15°, 30°, 45°, 60°, 75°and 90°.
5. Three trials per subject for each approach angle.
6. The testing in a field-based setting.

1.7 LIMITATION

Following were the limitations of the study: -

1. The ability of the subject to execute appropriate kick.
2. The validity and reliability of the biomechanical instrumentation.
3. Weather conditions such as rain, wind velocity and hot day etc. during testing program.
4. The accuracy of the researcher's ability to digitise the kinematic data.
5. The researcher's reliability in analysis and interpretation of the data.
6. Not using any special motivational methods will be again a limiting factor.

Chapter ii

LITERATURE REVIEW

The review of literature revealed numerous texts and articles that described the human performance involving all aspects of human activities such as walking, running and kicking. Generally investigations conducted in this area focussed on kinematic, kinetic and electromyographic analyses of different skills levels of sports and non-sports persons. The vast majority of research in sports biomechanics deals with kinematic analysis of relevant sports technique. The review of related literature is organised under the following headings, (a) Kinematics of walking and running (b) Kinematics of kicking, (b) Cinematography/ Videography and (c) Summary.

2.1 KINEMATICS OF WALKING AND RUNNING

The systematic investigation of human walking is known as gait analysis and without any doubt this gait has been observed ever since man evolved. Though early studies were mainly confined to general observation, it was Borelli in 1682 who became the first person to study the human gait in a truly scientific manner (Whittle, 1993). Since then numerous papers have been published on this particular area.

Human gait consists of two modes: walking and running (Winter, 1991; Enoka, 1994). One complete gait cycle (foot contact to foot contact of the same foot) is called a stride and one half cycle is known as a step. During support phase of gait cycle, the foot is in contact with the ground while in the swing phase, the foot is off the ground (Whittle, 1993; Enoka, 1994). Figure 2.1.1(a) shows major events of the gait cycle.

Figure 2.1.1(b) shows the angular displacement of lower limb for one complete running cycle of a runner. Hay (1993) described that in running events the primary objective of an athlete is to cover a set distance in the least possible time. Running speed depends on stride length and stride rate/ frequency (Vaughan, 1984; Hay, 1993). The running speed increases when stride length remains constant and stride rate increases. Similarly, if stride rate remains constant then stride length increases resulting increase in speed (Enoka, 1994). The stride length is again related with the range of motion about a joint (quantity) and the pattern of displacement (quality). As the runner goes from a walk to a run the angular displacement about the knee joint increases. Stance phase of gait includes both flexion and extension during walking and running but only extension in sprint. Likewise, the range of motion about both shoulder and elbow joints also increases as a person goes from walk to a sprint (Vaughan, 1984).

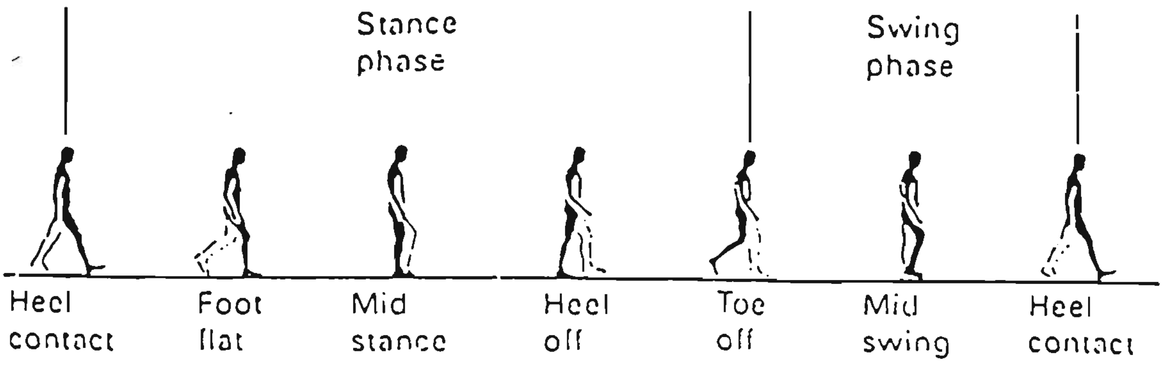


Figure 2.1.1 (a) Major Events of a Single Gait Cycle from Right Heel Contact to Right Heel Contact (Adapted from Whittle, 1993).

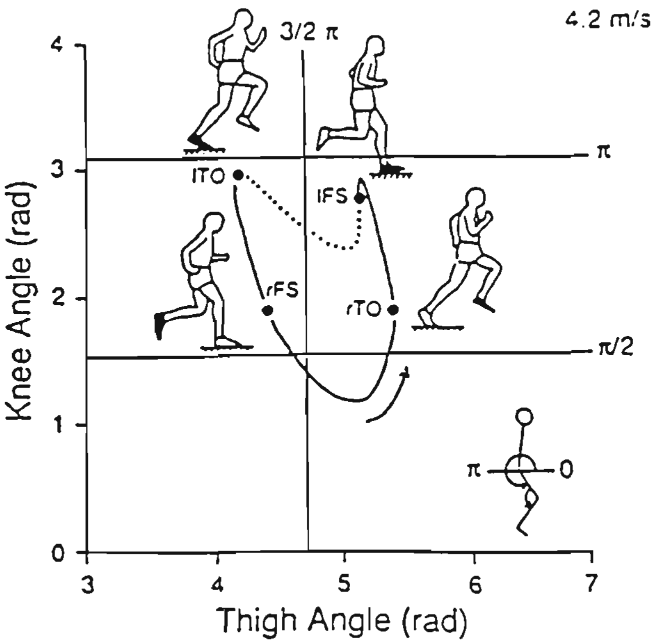
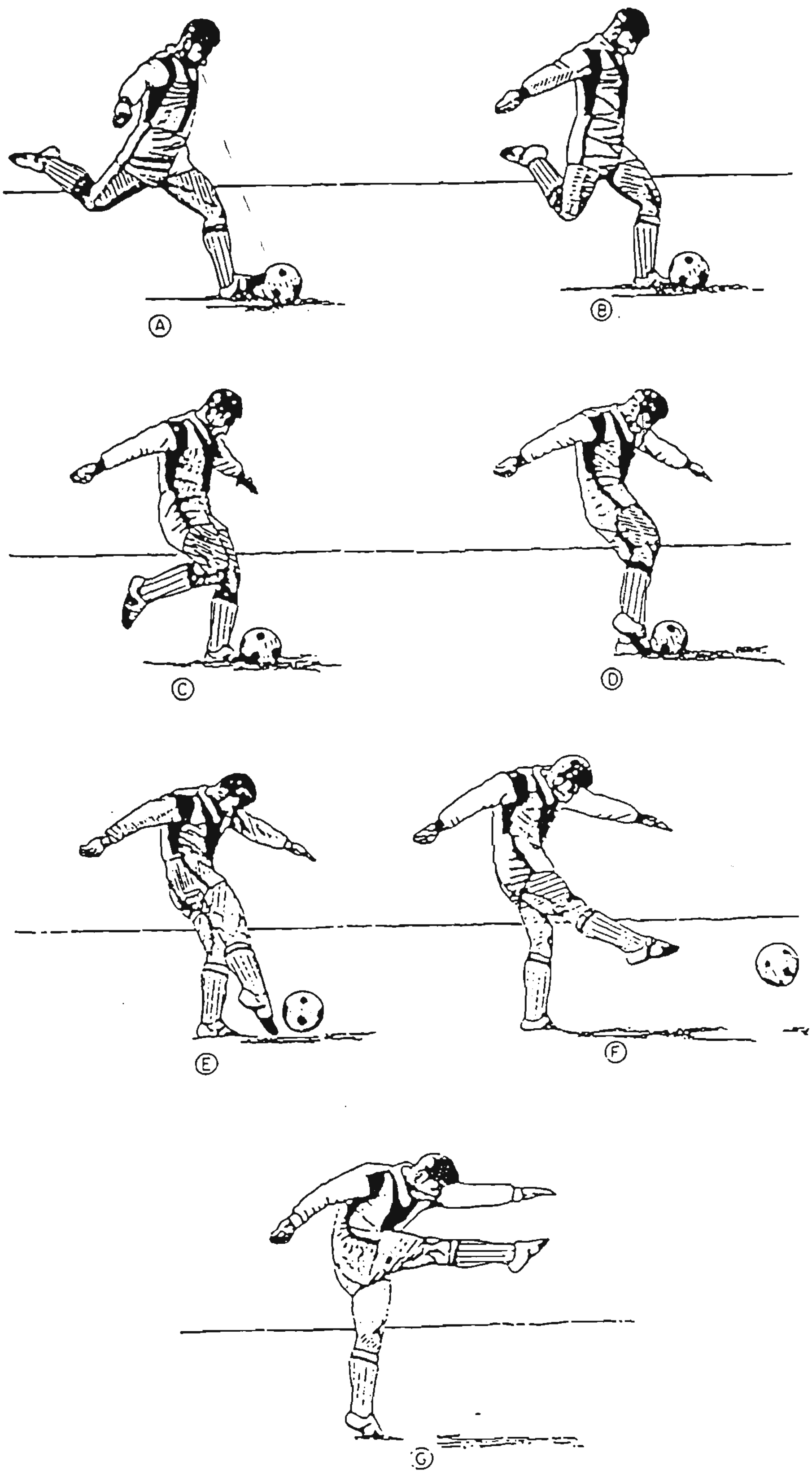


Figure 2.1.1 (b) Angular Displacement of Lower Limb (knee-thigh angle) for One Complete Running Cycle of a Runner (Adapted from ENOKA, 1994), TO = Toe-off, FS= Foot-strike, l = Left, r = right.

2.2 KINEMATICS OF KICKING

Kicking is considered to be one of the fundamental movement skills which human being utilises in various games and sports including soccer (see Figure 2.2.1). The kicking motion can be considered as a slight change of walking and running motion. It disagrees from walking and running in that the swinging of the kicking leg rather than the supporting leg generates the primary force of the kick. The movement of the kicking leg is also greater in kick than in a run or walk (Huang et al., 1982).

Since the beginning of the scientific research on soccer game kicking has been regarded without doubt the most widely studied skill. Soccer experts, coaches and physical education teachers have been extensively investigating better ways and means for teaching successful kick in soccer (Barfield, 1995; Lees, 1996). In order to execute technically and mechanically correct kick, some of the important factors should be given an emphasis. Such as the support foot placement and kicking foot rigidity (Hewlett and Bennet, 1951; Burdan, 1955; Dicle and Frank, 1971; Richard, 1971; Plagenhoef, 1971; Heyward, 1972; Asami and Nolte, 1983; Lees, 1985), velocities in the striking leg and relative contribution of each segment (Bunn, 1972; Huang et al., 1982), muscle strength (Hoshizaki, 1984; Cabri, 1983), striking mass (Sawhill, 1978), support leg position and knee joint angles (Heyward, 1972), angle of approach (Rexroad, 1968; Plagenhoef, 1971; Isokawa and Lees, 1988).



(A) The trunk and kicking leg revolve about the left hip and obtain a fuller back position of the right thigh, (B) The trunk and thigh rotate as one segment, until the full knee bend is reached, (C) Pointing of the thigh at the ball during the fast swing of the kicking leg, (D) Position of the non-kicking foot in relation to the ball and firm foot at impact, (E-G) The high follow-through

Figure 2.2.1 Instep Kick in Soccer (Adapted from Plagenhoef, 1971)

As described in the Ohio State University Scale of Intragross Motor Assessment (Loovis and Ersing, 1979), a kick is called mature when the player (a) swings the kicking leg backward with a bent and then forward with a simultaneous extension of the leg, (b) kept both the arms out to the sides of the body to maintain balance, (c) leans back little as kick is executed, (d) uses non-kicking leg to maintain balance during knee action and follow-through and (e) steps forward onto kicking leg, after kicking action and follow-through are completed. Though studies on the development of kicking (Butterfield and Loovis, 1994) among players between grades K to 8 (4-14 years) show a rapid development across grades K to 4, however performance level of player of grades 5 to 8 were inconsistent from year to year. The most important fact regarding the development of the kicking skill was that many player, even by grade 8, didn't achieve mature performance.

Wikstorm (1972) has described that in order to perform mature kick the placement of the non-kicking foot at the side and slightly behind the ball is imperative. In the execution of the kick the striking leg is first taken backwards and leg flexes at the knee. The forward motion is initiated by rotating around the hip of the non-kicking leg and by bringing the upper leg forwards. The leg is still flexing at this stage. Once this initial action has taken place the upper leg begins to decelerate until it is essentially motionless at ball contact. The leg remains straight through ball contact and begins to flex and foot often reaches above the level of the hip during the long follow-through.

Many researchers (Fabian and Whittaker, 1950; Hewlett and Bennet, 1951; Burdan, 1955; Dicle and Frank, 1971; Richard, 1971; Abo-Abo, 1981; Lees, 1985; Wang et al., 1994) agreed that for successful kick the non-kicking foot should be placed perpendicular to an imaginary line drawn through the ball. Heyward (1972) observed from his investigation with the female soccer players that when the support foot was placed anywhere in an area from six inches ahead to six inches behind the ball, there was no significant effect on resultant ball velocity. Cooper et al. (1982) reported that the placement of the non-kicking foot would vary according to the purpose of the kick. If the purpose is to perform a low trajectory kick, the non-kicking foot should be placed beside the ball; if the purpose is to perform a high drive kick, the non-kicking foot should be placed 4 to 6 inches behind a perpendicular line through the ball. When assessing high drive kicks versus low drives, at ball contact, Tant (1990), revealed that the trunk was more upright or leaning back and the knee was further behind the ball in the low drive kick.

Togari et al. (1972) elicited that though there was high correlation between foot velocity immediately before impact and kicked ball velocity, skilled players kick the ball with higher velocity than unskilled player's in-spite of the same foot velocity. They suggested that the rigidity of the kicking foot during impact was an important factor for a powerful kick as well as foot velocity. Shibukawa (1973) considered the body of the kicker at impact as a system of rigid bodies connected at three joints, the hip, knee and ankle and theoretically calculated the effect of foot velocity and joint fixation on ball velocity. He concluded that ball velocity was greatly influenced by joint fixation of the kicking leg as well as foot velocity at impact.

Wang et al. (1994) reported that for executing perfect instep kick a speedy and large final step of approach is crucial for creating a condition that allows the players to increase the velocity of the kicking swing motion. The kicking leg should swing from back to forward as fast as possible. The ankle of the kicking foot should be kept as firm as possible to avoid absorbing impact force which is important for executing maximum kicking power.

Barfield (1996) reported that in order to achieve optimal kicking performance players should strike the ball as close to the ankle as possible. The study carried out by Asai et al., (1996) also revealed that upper hitting (hitting the ball 0.03 m higher of the middle of the instep of foot) yielded maximum velocity of ball (37.31 m/s) after impact, followed by middle of the instep hitting (29.89 m/s) and lower hitting (24.89 m/s) (0.03 m lower of the middle of the instep of foot).

It is evident from the studies on curve ball kicking (Wang and Griffin, 1997; Asai et al., 1998) that if the ball is kicked laterally off-centre, which is also known as slice, the ball follows a curve path to one side. If the kick is executed across the ball from right to left it generate clockwise spin; counter clockwise spin produced by a kicking motion from left to right. The amount of spin of a curve ball in soccer is approximately 8 $rads^{-1}$ to 10 $rads^{-1}$ (Asai and Akatsuka, 1998). Wickstrom (1970) has also showed that the point of application of force influenced not only the speed but also accuracy of the ball. The final direction of the moving body would be a resultant of the magnitude and direction of all the forces, which were applied. In order to obtain maximum potential ball velocity, timing must also be considered. The contribution of the step (approach); leg swing and pelvic rotation should be integrated in order to obtain maximum linear velocity of the levers for the kicking action.

Huang et al. (1982) emphasized that the development of velocity in kicking leg at impact has been found to be the important in soccer kicking. The contributing factors to the swing velocity of the kicking limb at the time of instep kick are linear velocity of hip rotation as the kick begins, forceful hip flexion followed by extension of knee (Miller and Nelson, 1973; Philip, 1985; Weineck, 1986). The studies by Roberts and Metcalfe (1968) and Copper et al. (1982) also agreed that the hip action makes an important contribution in the early force-producing phase of the kick. As the thigh is swung forward by hip flexion, leg begins to rotate and carries the leg and foot with it. The knee extension starts the moment thigh past the perpendicular and become primary contributor in the final force-producing phase of the kick. The velocity of kicking leg is determined by the knee extension and hip flexion, although the latter action does not occur on impact pelvic rotation may be acting at the time of contact. However there is little or no hip action in the final phase. The ankle action of the kicking foot is used to position the foot for impact.

An the investigation conducted by Levanon and Dapena (1998) reported that in full instep kick as the kicking foot took off the ground pelvis started rotating backward and tilted leftward. During this period hip reached a maximum extension of -29° ± 13°, knee attained a maximum flexion of -113° ± 9° and a small motion of ankle extension (plantar flexion) occurred between take off and impact of the foot with the ball (75° ±

13° to 56° ± 3°). At impact (contact of the kicking foot with ball) pelvis virtually remained neutral but hip was flexed at 22° ± 9° with an angular velocity of about 1000 deg/s and a very rapid extension of knee was observed reaching an angular velocity of 1520 ± 400 deg/s. They also reported that flexion and extension at the knee made the largest contribution to the final speed of the kicking foot (86%). The ball velocity (M= 28.6 m/s) depended on the speed of the foot which was similar to the value reported by Plagenhoef (1971) and Roberts and Metacalfe (1968). These studies highlight the importance of knee joint angular motion in the kicking task and its contribution to maximum foot velocity. Anderson and Sidaway (1994) reported similar findings.

Opavsky (1988) conducted a study with six subjects, to investigate the linear and angular kinematic characteristics of standing and running kicks with the foot making contact with the ball on its dorsal surface. The running kick produced greater linear and angular velocities in the leg. However, the standing kick generated higher acceleration suggesting greater muscular efforts were being applied. Angular foot velocities in both kicks reached in excess of 20 rad/s. The ball velocity for standing approach kick was recorded 23.48 m/s and for running approach kick it was found to be 30.78 m/s. Ability to kick with increased velocity is, in part, dependent on the length of the lever arm of kicking limb (Cooper et al., 1982) and development, summation and application of force (Philip and Burke, 1965). The lower leg and the part of the foot between the ankle and the point of impact form the lever utilised in kicking. During the kicking, the length of the moment arm and the length of the lever are increased through extension of the lower leg prior to impact with the ball. The moment arm is that line which is perpendicular to the axis and to the direction of desired application of force. The length of the moment arm is approximately the distance from the knee to the point of impact. Moment arm length will differ on the length of the individual's body segment and the position of the body segments at the time of impact. Considering all other factors equal, the potential linear velocity at the end of the lever is increased when the length of the moment arm is increased. Since the length of the moment arm is partially dependent on the length of the lever, increasing the length of the lever increases the potential linear velocity at the end of the lever.

The resultant ball velocity is related to the force of each contributing body segment which is developed internally through muscular contraction (Bunn, 1972). The force is also dependent upon the mass and acceleration of each body segment. The sum of the linear velocities of each acting joint determines the resultant ball velocity of the kick. The primary contributors of force in the instep kick are reported to be hip flexion, knee extension and pelvic rotation. The summation of these three forces compose the force producing phase of the kick (Heyward, 1971).

There appears to be a direct relationship between muscle strength and performance for generating foot velocity (Lees, 1996). Several sport scientists have investigated this relationship. The high correlation between knee flexor extensor strength as measured by isokinetic muscle function dynamometer and distance covered by the ball (DCB) was reported by Cabri et al. (1988). They also found a significant relationship between hip muscle strength and DCB. Poulmedis (1988) and Narici et al. (1988) who used ball velocity as measures of performance have found similar result. Accordingly De Proft et al. (1988) found that over a season of specific leg muscle strength training, muscle strength increased and so also did kick performance as measured by DCB.

In successful kicking muscle fiber also plays an important role especially when maximum velocity is considered. Athlete with higher percentage of fast twitch fibers can produce greater muscle forces at faster velocities of contraction than those with low percentage of fast twitch fibers. Positive contributions to performance level mainly rely on fatigue, fiber composition and adaptation to training conditions. Characteristics of muscle fiber composition are critical determinants in athletic performance (Forsberg et al., 1976; Gollnick, 1983).

Clarys et al. (1985) elicited that during a soccer kick muscular activity at the knee joint demanded extensor muscles to be active during flexion and flexors to be active in extension motion. Except for the initial part of kicking motion, when the knee begins to flex, muscle torque is determined by eccentric activity in the extensors and not the flexors. Later when knee is vigorously extended in order to have an impact with the ball muscle torque controlled by concentric extensors activity (Enoka, 1994).

Asami and Nolte (1983) carried out an investigation with four German soccer players (one professional, one international and two amateur level), they were instructed to kick a placed ball as powerfully as possible at the center of a handball goal placed at 10 m apart. Measurements were made of ball velocity, foot velocity before and after impact, ratio between ball velocity and foot velocity before contact, striking mass, impact time, mean force applied between foot and ball during impact, maximum angular displacement of ankle and foot during impact and vertical force of non-kicking foot at impact. They found a ball velocity of 34 m/s and average ratio of ball velocity to foot velocity before contact was 1.06 which was lower than reported by others (Plagenhoef, 1971; Shibukawa, 1973). Their foot velocity was found to be decreased from 28.3 to 15.5 m/s, while Plgenhoef's (1971) data decelerated from 24.1 to 21.0 m/s during impact. These results suggest that rigidity of the foot is more important than ankle fixation for a powerful kick, although the latter affects ball velocity to a certain extent.

Although the above studies showed high relationship between the muscle strength and performance, however there are also other factors, which contribute to successful kicks. These factors are appreciated from a consideration of the relationship between foot and ball velocity before and after impact with the ball (Lees, 1996). By considering the mechanics of collision between the foot and ball, the velocity of the ball can be stated as:

$$V_{(ball)} = V_{(foot)} \frac{(M).(1+e)}{(M+m)} \qquad \text{.................(1)}$$

Where V = velocity of ball and foot respectively, M= effective striking mass of the leg, m = mass of the ball and e = coefficient of restitution.

The effective striking mass is the mass equivalent of the striking object and in this case the leg which relates to the rigidity of the limb (Plagenhoef, 1971). To achieve optimal performance in kicking striking the ball as near to the ankle as possible rather than behind is also very important (Barfield, 1996).

The term M/ (M+m) in equation (1) indicates the rigidity of impact and relates to the muscle involved in the kick and strength at impact. Therefore one would expect that the best correlation with performance would be with eccentric muscle strength and this has been confirmed by Cabri et al. (1988). The term (l+e) relates to the firmness of the foot at impact. Because the ball is on the ground, the foot contacts the ball on the dorsal aspect of the phalanges and lower metatarsals. The large impact serves to forcefully plantarflex the foot and it will do so until the bones at the ankle joint reach their extreme range of motion. At this stage the foot will deform at metatarsal phalangeal joint. There is little to prevent considerable deformation here and this will affect the firmness of impact and the value of "e" (Lees, 1996). Asami and Nolte (1983) measured the amount of deformation at both ankle and the metatarsal phalangeal joint and found that while the change in ankle joint angle did not correlate at all with ball velocity, the change in angle at the metatarsal phalangeal joint correlated highly with ball velocity. They concluded that the deformability of the foot should be reduced for powerful ball kicking and that this deformibility is related to the deformation at the front of the foot.

Plagenhoef (1971) conducted a research with a single subject in order to measure the quantity of striking mass. He reported that the instep kick taken from a side or pivot recorded highest in striking mass value for all the kicks tested with an average of 3.9 kg. The striking mass of the straight instep kick averaged 3.2 kg. In computing striking masses, Plagenhoef measured foot as well as ball velocities. Bensira (1980) elicited that striking mass equated the product of the ball's mass before and after impact (see equation 2 below). Striking mass may also be considered as a function of the ball's velocity before contact divided by loss in the velocity during impact (Sawhill, 1978).

$$m_{21} = m_1 \frac{v_3}{v_2 - v_4} \qquad \text{....................(2)}$$

m_2 - striking mass

m_l - mass of ball

v_3 - ball velocity after impact

v_2 - velocity of striking mass before impact.

v_4 - velocity of striking mass after impact (Sawhill, 1978).

Apart from considering the above factors it has also been noticed that effect of air resistance on the angle of projection plays a vital role in successful kick. An investigation done by Colfer and Dowell (1977) examined the effect of air resistance on angle of projection and range of a place kicked football. The purpose was to determine K (the effect of air resistance) for a placed kick football and to determine the deviation from 45° of the initial angle of projection. With a film speed of 64 frames per second, a 16mm Bolex reflex camera recorded five kicks travelling over 50 yards and the kicks were analysed. They found that the mean angle of projection for the place kick were 29° which was below the theoretical 45°, while the mean initial velocity was 49.07 m/s. The mean K value was .26 indicating that a place kick in air travels approximately 1/4 as far as it would travel in a vacuum. Therefore, it may be concluded that air resistance drastically affects the trajectory of a place kicked football.

In the study conducted by Barfield (1993) reported that there exist a relationship between the velocity of ball and the kinematic variables of the dominant side of the kicking limb. The kinematic variables that were correlated are maximum linear velocities of toe (M= 21.50 m/s), knee (M= 10.05 m/s) and linear velocities of toe (M= 19.17 m/s) and ankle (M= 15.50 m/s) and angular velocity of knee (M= -1599.03 deg/s) at ball contact. Further he reported that at ball contact the linear velocity of the toe and the angular velocity of knee attained maximum for dominant leg. The release velocity of the ball is also correlated significantly to body anthropometrics (weight, r=0.928; height, r=0.911; age, r=0.932) and also it is highly correlated to the maximal moments produced during hip flexion (r=0.932), knee extension (r=0.937) and ankle stabilization (r=0.935) in the kicking limb (Luhtanen, 1988).

A few studies have investigated the effect of approach angles on ball velocities in soccer. Moudgil (1967) compared two styles of instep kicking, the straight and the pivot approach, through the use of electrogoniometry. He found a significant difference between the two angles. The pivot instep kick generated a higher average ball velocity of 21.93 m/s than the straight instep kick, which generated a ball velocity of 18.94 m/s.

Rexroad (1968) conducted a study on pivot instep kick and found the linear velocity of the kicking foot as it approached the ball varied between 18.07 m/s and 21.48 m/s. Also the resulting ball velocities ranging from 23.70 m/s to 25.30 m/s. Plagenhoef (1971) and Asai et al. (1980) investigated the effect of straight and diagonal approaches on ball velocity and leg swing velocity. These studies concluded that the diagonal approach caused greater ball and leg swing velocities than the straight approach. Gibson (1985) also concluded that angled approach produces more powerful kick than straight approach. But how angular changes in approach would affect the ball velocity or the kick has not been explored in these studies. With twenty high-school right-footed soccer players Levy (1995) conducted a study in order to examine the effect of target locations and kicking techniques on approach angle. The research concluded that players tend to approach the ball differently depending on the target locations.

Isokawa and Lees (1988) were the first to carry out a comprehensive study on the relative influence of different approach angles on ball velocities. Their subjects were six male soccer players ranging in age from 20 to 36 years. The kicking motions were recorded from the side by a 16-mm Locam camera operating at 150 frames per second. Players were required to take one step approach in order to kick a stationary ball from angles of 0°, 15°, 30°, 45°, 60° and 90°. The maximum swing velocity of the leg was achieved with an approach angle of 30° and the maximum ball velocity (M= 20.14 m/s) was recorded for an approach angle of 45°. However these results were not significantly different for the various approach angles. It was concluded that approach angle between 30° to 60° would be likely to produce maximum ball velocity while minimising torque applied to the foot. This study was conducted with limited number of subjects and also only 2-Dimensional data were analysed. These might have contributed to non-significant differences between different approach angles. Soccer kick executed from angled approach generally involve rotation of the whole body and therefore needs 3-Dimensional analysis in order to investigate the complex movement of the rotational affect of different joints and segments of the player.

2.3 CINEMATOGRAPHY/ VIDEOGRAPHY IN BIOMECHANICS

Cinematography has been a major research tool in the analysis of human movement. It allows measurement to be taken from the final film product (Sawhill, 1978). When it is used, the subject can be observed under natural or laboratory conditions without interference from instrumentation (Miller and Nelson, 1973). This has enabled the coaches and physical education teachers to analyse the fundamental principles of motion to complex movements with great accuracy (Sawhill, 1978). These qualities of cinematography encouraged Muybridge (1878) to apply photographic processes to the assessment of horse to find out whether a horse's four hooves came off the ground and caused it to be airborne during any phase of its motion. A series of single shots were taken using still cameras along the path of the horse, set them off sequentially to determine from the developed prints if all four hooves were off the ground at any one time. These techniques of sequentially triggering still cameras were later used to study human motion.

In the 1880's Marey became the first individual to employ photographic technique to study human motion. He contributed further refinement to Muybridge's pioneering efforts by making specific anatomical landmarks on his subjects so that their locations might be found easily in the later analysis. From these innovations, total motion of the human body could be viewed as the composite motions of many body parts.

For the next fifty years, photographic analysis of motion was developed as the importance of its application became wide spread (Sawhill, 1978). In the late thirties, Cureton (1939) became the first physical educator to describe the formal procedures for performing cinematographical analysis. He stated:

> "Fairly precise analysis of the external mechanics of many acts of skill may be made by cinematography. The fundamental principle is that direction of movement (angle), dimension, time relations, and indirect values of force and velocity may all be obtained from he projected film. Since the science of mechanics is an expression of the laws of physical equilibrium or movement in terms of the same fundamental or derived measurements, a mechanical analysis of any movement may be made from measurements taken from the screen. Cinematigraphical analysis consists of the technique for making these measurements".

Through this investigation Cureton (1939) also able to trace out some of the major problems such as the timing, the measurement of angle, perspective error, film deformations, lens aberrations and scaling associated with planner cinematographical analysis. Since the mid sixties, when Plagenhoef (1966) re-examined cinematography as a tool for quantifying human motion, many reports have been published by sports scientists which extensively described the cinematographical technique (Tant, 1990).

Walton (1981) reported that in two-dimensional planar analysis, a multiplier was used to convert film images to real scale values. A single camera was placed at a specific distance from a subject and aligned perpendicular to the plane of motion. Also a rigid bar of known length was placed in the plane of the motion and then filmed. While data reduction, the image length of the bar was used in conjunction with its known length to obtain a single scaling coefficient, which was called a multiplier. This multiplier was then used to convert displacements in the film image to real scale displacements in the plane of motion.

If, however the film plane of the camera was not parallel or the movement violated a planar motion, perspective errors would occur (Tant, 1990). Several researchers (Noss, 1967; Plagenhoef, 1968; Doolittle, 1971) have investigated the perspective error problem. It seems that the exclusive solution to the perspective error problem is three-dimensional cinematography (Tant, 1990). Important information about twisting or diagonal actions in different planes of a movement cannot be obtained by using only one camera in planar film analysis (Miller and Petak, 1973). Therefore by using two or more cameras, in a three-dimensional technique, one could give reckoning of the depth of an image and eliminate perspective errors (Tant, 1990).

In the early seventies, several researchers (Miller and Petak, 1973; Bergemann, 1974; Van Gheluwe, 1974) put forward for consideration of three-dimensional technique for analysis of human movement. Miller and Petak (1973) conducted a study by setting-up three cameras in a way so their optical axes were horizontal and intersected at a single point. Each camera was sighted along its own positive Y-axis. One camera was used as the main reference camera with other two cameras rotated at 120-degree angle. A rifle target was positioned beyond the origin and aligned with the optical axis of each camera. A surveyor's transit was set at a specified origin of the spatial coordinate system. The correct vertical alignment was obtained by sighting a plumb line placed on the target centre. An arbitrary point was photographed in all cameras with the point of intersection of the camera axes the origin. The object coordinates were obtained in relationship to the origin. Linear interpolation was used to time-match the data recovered from the three cameras. Validation of the system was mentioned, but no information was provided as to how this was carried out.

Bergemann (1974) attemted to eliminate the restrictions on camera placement. The accuracy of this technique was highly dependent on how accurate all the coordinates could be determined. The coordinates of the vectors were first found with respect to reference planes aligned parallel to the film plane of each camera. These coordinates were then transformed and expressed with respect to the object-reference-frame. The multipliers used by Bergemann were determined by using a circle with its center at the origin of the object-reference-frame. The circle was drawn on a flat surface and contained within the field of view of each camera. The circle appeared as an ellipse in the photographic image. The image length of the major axis of the ellipse was the image length of the true diameter of the circle. This was then used as a multiplier for each of the views.

Van Gheluwe (1974) was the first sports scientist to establish depth scaling by using object-space control points; but in doing so principal distance of each camera had to be known and camera axes still were required to pass through the origin of the object-reference-frame. He used the least square approximation to estimate the desired object coordination.

Earlier, several sports scientists (Miller and Petak, 1973; Bergemann, 1974; Van Gheluwe, 1974) developed cinematographical techniques for both planar and three-dimensional analyses. However, these investigators had not utilised the important information available in the photogrammetric literature. Walton (1981) described that close-range photogrammetry, obtaining information about physical objects through photographic images, should be of interest to the sports teachers/ coaches. The method applied during photogrammetric techniques needs expensive metric cameras and this happened to be a restrictive measure for the analysis of human movement (Tant, 1990).

Among the various three-dimensional photography methods that have been developed, DLT (Direct Linear Transformation) approach proposed by Abdel-Aziz and Karara (1971) appears to yield accurate results (Shapiro, 1978; Marzan and Karara, 1975; Miller et al., 1980; Hatze, 1988; Chen et al., 1994). The DLT technique method was originally proposed for still cameras. Abdel-Aziz and Karara (1971) reported that a simple model with only one correlation coefficient for image deformation was sufficient for accurate results. Marzan and Karara (1975) developed a computer programme to be used in conjunction with high-speed cinematography technique.

Before the development of the DLT technique, the absence of flexibility in three-dimensional technique was a major prohibiting factor in conducting biomechanical research (Tant, 1990). Complicated and tedious set-up procedures (Miller and Petak, 1973; Bergemann, 1974; Van Gheluwe, 1974) involved in the investigation discouraged many sports scientists from answering questions related to three-dimensional movements. Shapiro (1978), Walton (1979, 1981b) and Chen et al. (1994) evaluated and refined the DLT method for use with high-speed cinematography/ videography.

Shaprio (1978) reported fundamental information concerning the DLT technique, but Walton (1979, 1981 b) thoroughly investigated and developed the DLT method for high-speed cinematography. In Shaprio's procedure he utilised two high-speed cameras while filming a reference structure with known spatial coordinates. The cameras were fixed in a position so that the distance between cameras (base ratio) was approximately one-third the perpendicular distance from a line between cameras to the object. The reference structure was removed, after the control points were filmed. These control points enabled the determination of interior and exterior camera orientations. Standard film analysis techniques were utilized to obtain X and Y film coordinates. At least six non-coplanar control points were utilised to develop a set of 12 equations for each view. Spatial coordinate calculations were based on knowledge of film coordinates (x_i, y_i) of the i^{th} point and the object space coordinates (X_i, Y_i, Z_i) of the i^{th} point. The coordinate data used as input to the DLT equations (Shapiro, 1978):

$$x_i + L_1X_i + L_2Y_i + L_3Z_i + L_4 + L_9x_i X_i + L_{10}x_i Y_i + L_{11}x_i Z_i = 0 \qquad (3)$$

$$y_i + L_5X_i + L_6Y_i + L_7Z_i + L_8 + L_9x_i X_i + L_{10}x_i Y_i + L_{11}x_i Z_i = 0 \qquad (4)$$

Where L_1 through L_{11} are the unknown DLT parameters. A minimum of six control points are required to determine a solution for each DLT parameter. Once the DLT parameters are known, the x and y film co-ordinates for each unknown point can be entered into the same equations and the spatial co-ordinates (X, Y, Z) of the points can be determined.

Shapiro conducted three validation tests, (two static and one dynamic) in order to evaluate the DLT method with high-speed cinematography. In the first test 48 stationary points were filmed; out of which only 20 were selected to predict the DLT parameters and rest were treated as unknowns. The average errors associated with the X, Y, and Z co-ordinates for the 28 unknown points were 0.43 cm (X), 0.51 cm (Y), and 0.44 cm (Z). In the second static test he used a meter stick placed at the extreme edge of the photographic field to test co-ordinates outside of the control object space. The calculated length of the meter stick was found to vary by 2% to 4% from the known length. The dynamic test was conducted by filming a golf ball falling in free flight. The acceleration of the ball found to be ranged from $-9.5\ m/s^2$ to $10.0\ m/s^2$. These calculated vertical accelerations were within 1% to 4% of the value of gravitational acceleration of $-9.8\ m/s^2$.

From this Shapiro's study several concerns for using the DLT method with pin-registered motion picture cameras were addressed. At the very beginning, the degree of error was found to be within ± 0.5 cm of locating the unknown spatial co-ordinates. Next the effect on accuracy of unknown points located in the extreme areas of the photographic field were found to be below 5%. Shaprio recommended that control points should be located throughout the photographic field. At last it has been observed that vertical accelerations were within 5% of the criterion value of $-9.8\ m/\ s^2$ for a dynamic movement. The accuracy of measurement of the DLT method was similar to other reported three-dimensional techniques. Flexibility was the main advantage addressed as the benefit of the DLT method. After constructing the control point system, one must only need to be careful that each point to be located on the object was visible in both cameras.

Walton (1979, 1981b) has offered enormous information of the theoretical and practical application of DLT technique to high-speed cinematography. The elementary optical geometry of an idle non-metric camera and an ideal motion analyser helped him in obtaining the fundamental information required to develop the appropriate mathematical model of the photo-optical systems. Like Shapiro (1978) he also followed the same procedure for camera set-up and filming of control objects. However, several other important informations on cameras, lenses, control points, film and temporal measurements were provided. Every camera should be operated electronically with frame rates kept as high as possible in order to decrease error in time-matching data and shutter factors should be computed accurately. Three lens factors should be considered: (a) focal length, (b) maximum relative aperture and (c) maximum relative distortion. Accurate location of control points happened to be an important section of the experimental process. Excellent results were obtained when the control points were well distributed in the control space.

With reference to the camera image, three vectors (n_x, n_y, n_z) and an origin point (A), defined a three-dimensional reference frame fixed in the object space. All the points within this object space have three-dimensional object co-ordinates (object-reference-frame). N_u and N_v are unit vectors parallel to the image plane, which defined a two-dimensional reference frame of digitizer co-ordinates (image-reference-frame). The general form required for object-to-image transformation was (Walton, 1981b):

$$U = \frac{Ax + By + Cz + D}{Ex + Fy + Gz + 1} \quad \text{..................(5)}$$

$$V = \frac{Hx + Jy + Kz + L}{Ex + Fy + Gz + 1} \quad \text{....................(6)}$$

Specific values must be provided for the calibration coefficients of A through L from transformation matrices. Three-dimensional object-co-ordinates must be determined with the use of two cameras. If the data from different cameras were time-matched, a set of equations were combined and found to be over-determined. Specific estimates for X, Y, and Z could be obtained using a linear square approximation.

In order to obtain accurate 3-D results it is important to gather time-matching data from different sources. Time-matched co-ordinates could be achieved by one of the following three procedures: (a) synchronised camera shutters (b) split-image camera configuration and (c) mathematical interpolation co-ordinates (Walton, 1981b).

Several authors using the DLT technique have demonstrated that it yields excellent results for both video and film systems in the control region (Shapiro, 1978; Walton, 1979, 1981b; Wood and Marshall, 1986; Hatze, 1988; Kennedy et al., 1989). They observed that the standard DLT technique yields decreasing accuracy as one approach the extremes of the control region and the accuracy was further limited outside the control region. They all acknowledged that, while more control points could improve the calibration accuracy, it was more important to have well-distributed control points than to just increase the control points. Also accuracy is dependent also on angle between the two camera axes with best results at $\theta = 90°$ (Chen, 1994).

Since only limited number of configurations of control points were tested in those studies and the equipment varied considerably, it was difficult to determine the relationship between calibration errors and control point configuration. An investigation on the three-dimensional calibration errors associated with DLT technique carried out by Chen et al. (1994) had revealed some of the important information on this topic. Two video cameras were used for the test. Thirty different configurations in five groupings of different numbers of control points were tested. They found that the accuracy improved as the number of control points increased from 8 to 24. Further it was reported that the best accuracy was achieved when the control points were evenly distributed throughout the control region. An accuracy of 1-2 mm in the X and Y directions, 4-6 mm in the Z direction and 6-7 mm for the resultant was obtained in a control space of 2.10 x 1.35 x 1.00 m. Additionally, they also found that the accuracy for points outside the control space abruptly decreased. A reduction of 20-40% calibration errors could result when an appropriate quadratic function was used to modify the standard DLT method.

2.4 SUMMARY OF LITERATURE REVIEW

The extensive literature review reveals that most of the investigators focused their studies only on the mechanics of instep kick in relation to the ball velocity. A few investigators (Moudgil, 1967; Rexroad, 1968; Plagehoef, 1971; Asai et al., 1980) studied the influence of approach angle on ball and leg velocities. These studies have demonstrated the influence of approach angles on ball and leg velocities. It is not known, however, how angular changes in approach will affect other kinematic variables. Investigation carried out by Isokawa and Lees (1988) did elicit the importance of approach angle in instep kick in order to generate the maximum ball velocity. They omitted the important fundamental skills that govern the success of soccer game i.e. distance covered by the ball and accuracy of the instep kick. It should also be noted that these investigations are limited to two-dimensional kinematic analyses (which ignores rotational effect) and also with small sample size which might have affected their results.

Several researchers (Doolittle, 1971; Noss, 1967; Plgenhoef, 1968) examined the perspective error problem occurred in two-dimensional studies. It appears that the only complete solution to this perspective problem is three-dimensional studies (Tant, 1991). A single camera in planner film analysis cannot provide information about twisting or diagonal actions in different planes of a movement (Miller and Petak, 1973). Two or more cameras, utilised in a three-dimensional measurement technique could provide a better understanding of complex movement (Allard et al., 1995). The soccer instep kick involves complex movement of the whole body specially the lower extremity; thus a three dimensional measurement technique is required for a thorough analysis of this activity. To date no study has been reported on the three dimensional biomechanical aspects of the instep kick activity and the relative influence of approach angles on distance covered by ball and accuracy of the kick. The current study should add knowledge in the area of biomechanics of soccer kick.

Chapter iii

PROCEDURES

The purpose of the study was to analyse selected kinematic parameters of the lower extremity during the three-dimensional motion of instep kick taken from different approach angles.

Description of the experimental equipment and procedures used in the investigation are contained in this chapter. This chapter is divided into the following sections: (i) general procedure, (ii) selection and description of instrumentation, (iii) data reduction and analysis, (iv) kinematic analysis and (v) statistical procedures (vi) accuracy and reliability testing of kinematic data.

3.1 GENERAL PROCEDURES

The general procedures that were followed during this investigation are presented in this section. The section is divided into six subsections: (a) human subject approval, (b) preliminary investigation, (c) selection of subjects, (d) filming procedure and (e) selection of trials and frames for analysis.

3.1.1 Human Subject Approval

In order to involve human subjects in the investigation an approval from the Human Research Ethics Committee, Victoria University of Technology, Melbourne was obtained. Prior to the experiment subject's consent was also obtained, following an explanation of the nature and purpose of the study, by signing the VUT " Informed Consent Form" (Appendix A).

3.1.2 Preliminary Investigation

Prior to the actual data collection a preliminary investigation was conducted in order to tackle the possible hindrances concerning the experimental set-up. Applying a different camera positions and focus setting, one male soccer player was filmed while performing the instep kicks from approach angles (AA) of 0, 15, 30, 45, 60, 75 and 90 degrees (see Figure 3.2.2.1.1). The areas of investigation included were (a) determination of optimal locations for both cameras, (b) determination of the correct aperture and focal setting for each lens, (c) determination of the correct film speed and field of view, (d) determination of appropriate lighting, (e) approach angle and trial identification location and (f) familiarisation of the investigator and research assistants with the experimental equipment.

As a result of the preliminary investigation, the investigator and research assistants became familiar with the equipment used for the study. The correct lighting, aperture and focus settings ensured appropriately exposed film to aid in the digitising process.

Two research assistants were trained in the collection of data pertaining to distance covered by the ball and the accuracy of the kick. The preliminary investigation helped to reduce many problems that could have occurred during the actual data collection session.

3.1.3 Selection of Subjects

The selection of subjects were initiated through telephone contacts with the coaches of division IV State Soccer League, Victoria. The Coaches provided names and telephone numbers of potential subjects who were free of any injury in the lower extremities. In order to maintain homogeneity only right-footed kickers were selected for the study. The investigator contacted altogether twenty-three players as subjects for the study out of which twenty subjects participated in the investigation.

3.1.4 Filming Procedure

The film recording was conducted on a sunny and clear weather in the Football Ground of the Victoria University of Technology, Melbourne. All together three sessions were required in different days to complete the video recording. The average wind velocity and the weather temperature during the filming session were 0.75 m/s and 19.76° celsius respectively. Subjects were instructed to wear complete soccer kit in order to perform successful instep kick. They were shown the test facilities and procedure to be used, which included a demonstration of what was required of them. The players undertook practice trials prior to the actual filming session. Each subject performed three instep kicks from the designated approach angles. The order of the kicks was randomly assigned for each kicker. Each subject was permitted a two step approach to the ball, kicking it at maximum effort along the direction of target. All the subjects were given to kick the same standard ball (weight 450 grams and 10 psi air pressure).

3.1.5 Selection of Trials and Frames for Analysis

The distances of all three trials were recorded by measuring tape. The measurement was taken from the point of kicking to the point of landing of the ball was taken as the maximum distance covered by the ball (DCB). The perpendicular distance from the point of landing to the plane of activity was measured to indicate accuracy (AC) of the kick as proposed by Ahrari (1984). The ball landing within the minimum distance from the plane of activity was considered as the best accuracy. The best trial for each of the seven approach angles (0°, 15°, 45°, 60°, 75° and 90°) was selected for kinematic analysis. The best trial was determined based on the maximum distance covered by the ball that landed within the range of 7.3 m (width of standard goal post) from the plane of activity. In extreme cases where players couldn't achieve this accuracy, the nearest accuracy was taken for analysis.

During the film analyses specific video fields were selected. The ground contact by heel of the kicking foot and ball contact/ take-off was selected as the beginning and ending of the kick sequence respectively. The sequence of the kicking motion was divided into four phases/ events (Brown and Williamson, 1991): (a) Approach (ground contact of the kicking foot to ground contact of the non kicking foot along side the ball); (b) Pre-

Impact (ground contact of the non-kicking foot to before contact of ball with the kicking foot; (c) Impact (ball contact with kicking foot) and (d) Follow-through (ball contact/ strike to ball take-off). Five video fields prior to heel contact and five following the ball take-off were included in the video digitising process.

3.2 SELECTION AND DESCRIPTION OF INSTRUMENTS

The selection and description of instrumentation used during this investigation involved two sections. These were as follows: (i): Anthropometric measurements and (ii) Videography technique.

3.2.1 Anthropometric Measurements

Subject's body height and length of lower limb segments were recorded as outlined in Table 3.2.1.1. The body mass of each of the subject was recorded in kilogram (kg). The measurements were recorded by using the standard anthropometric kit available in the VUT biomechanics laboratory.

Table 3.2.1.1 Anthropometric Measurements

Measurement	Abbreviation	Definition
Stature	STA	Distance between the top of the head and the floor
Thigh Length	THL	Distance between greater trochanter and lateral epicondyle of femur
Lower Leg Length	LLL	Distance between medial epicondyle and medial malleos
Ankle Height	AkH	Distance between Medial malleous and sole of the foot.
Leg Length	LL	Greater trochenter to the sole

3.2.2 Videography Techniques

The videographic technique is further organised into four sections. These are:- (a) Videographic Equipment, (b) Camera Speed and Synchronisation, (c) Subject and Trial Identification and (d) Reference Frame Equipment.

3.2.2.1 Videographic Equipment and Location

The subject's kicking motion was recorded using two Synchronised Panasonic F15 S-VHS video cameras in a field setting. The videotapes used were TDK E180 Extra Grade videotapes. The cameras were set-up on a rigid tripod and secured to the floor in the location shown in the Figure 3.2.2.1.1. In order to obtain maximum accuracy in the reconstruction of the three-dimensional co-ordinates, the location of the cameras were chosen such that the optical axes of the cameras intersected at 90 degrees at the centre of field of view (Borghese and Ferrigno, 1990). Both the cameras shared a common field of view of approximately five meters. The cameras were operated by two experienced research assistants and were started on a signal from the principal investigator. After a signal was given for the cameras, the subject began to execute the whole range of the kicking motion.

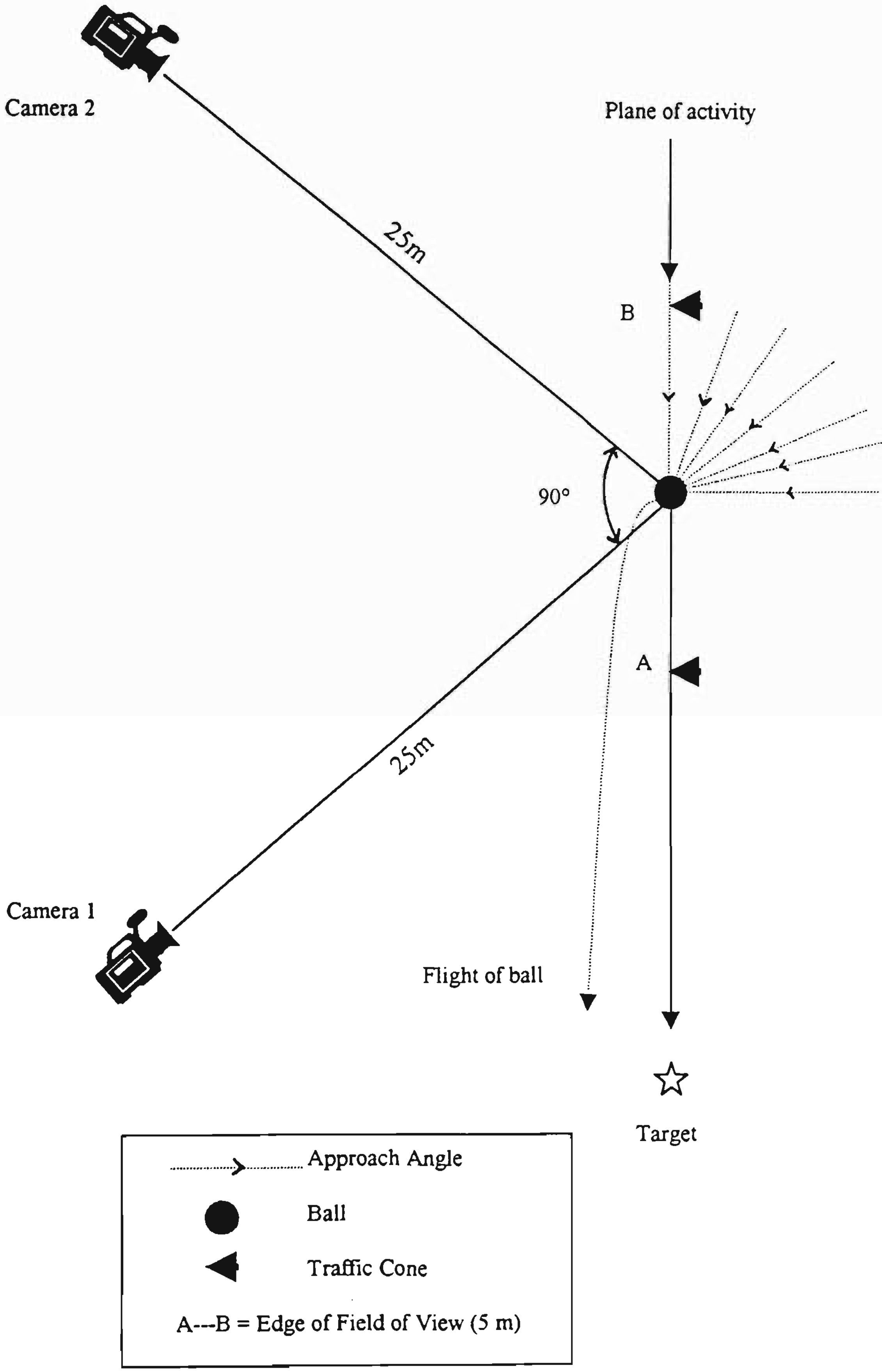


Figure 3.2.2.1.1 Plan View of Equipment Set-Up for the Experiment

3.2.2.2 Camera Speed and Synchronisation

The sampling rates of the video cameras were 50 fields per second (25 frames per second). The shutter of the cameras were fixed with a high speed (1/1000th of a second) in order to eliminate the effect of blurring while video recording. The tasks of synchronisation of the cameras were completed through the PEAK System's Event Synchronisation Unit (ESU).

3.2.2.3 Subject and Trial Identifications

For identification purposes a three-digit number was used for each trial. These numbers represented the subject, trial kick and approach angle of kick. These markers were placed on a take-board in the field of view of the cameras.

3.2.2.4 Reference Frame Equipment

Prior to the actual video recording of the instep kick motion the 3-D calibration frame of PEAK Motion Analysis System (Peak Technology Inc., USA) consisting of 24 spheres of known co-ordinates (see Figure 3.2.2.4.1) was filmed. This enables to have a life size scaling factor and permitted to convert screen co-ordinates of joint centres or limb segments data to actual 3-D spatial co-ordinates via DLT techniques as described in section 2.2. This is one of the frequently used technique in the area of biomechanics to reconstruct three-dimensional co-ordinates from multiple two dimensional views. The

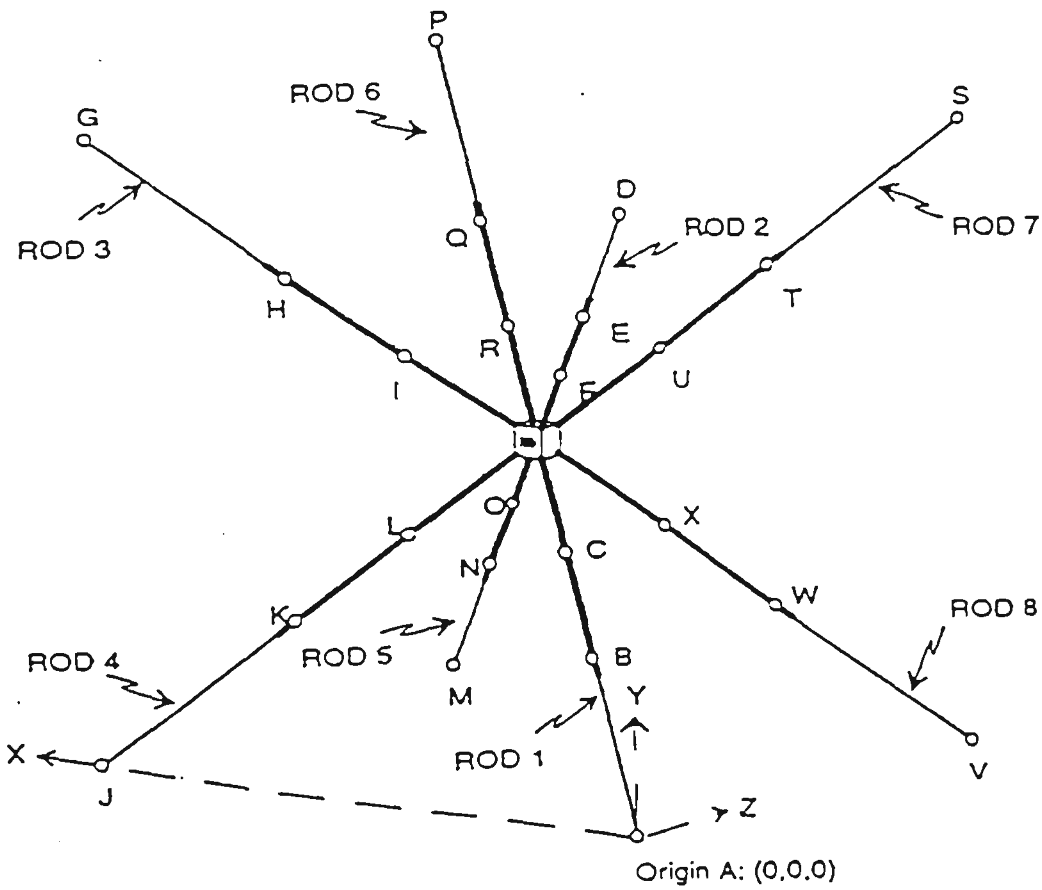


Figure 3.2.2.4.1 PEAK System Calibration Frame (Adapted from PEAK 5, 1993)

specification of X, Y and Z co-ordinates for kicking motion analysis are shown in Figure 3.2.2.4.2. By using relative angles at joints with three points in space, the joint angular data were calculated. Out of which one of the point represented as axis (joint centre) and the rest of the points set up extreme points of the two adjacent segments. The reference models for the hip, knee and ankle angular data are presented in Figures 3.2.2.4.3, 3.2.2.4.4 and 3.2.2.4.5 respectively.

3.3 DATA REDUCTION AND ANALYSIS

The analysis of the recorded data and the determination of the smoothed two and three-dimensional co-ordinates for the kicking leg are described in this section. The sequence of procedures that were followed are: (i) Analytic software (ii) Application of DLT Technique and Digitising of DLT Control Object, (iii) Digitising of the Instep Kick, (iv) Smoothing of the Data and (v) 3D Data and Parameter Calculations.

3.3.1 Analytic Software

After the video recording session was over, the following software was used to analyse the recorded data: (a) PEAK System Software and (b) SPSS Software. Twenty-two data points (see section 3.3.3) were manually digitised for each video field using PEAK software program. Frames were digitised sequentially one frame at a time for each trial.

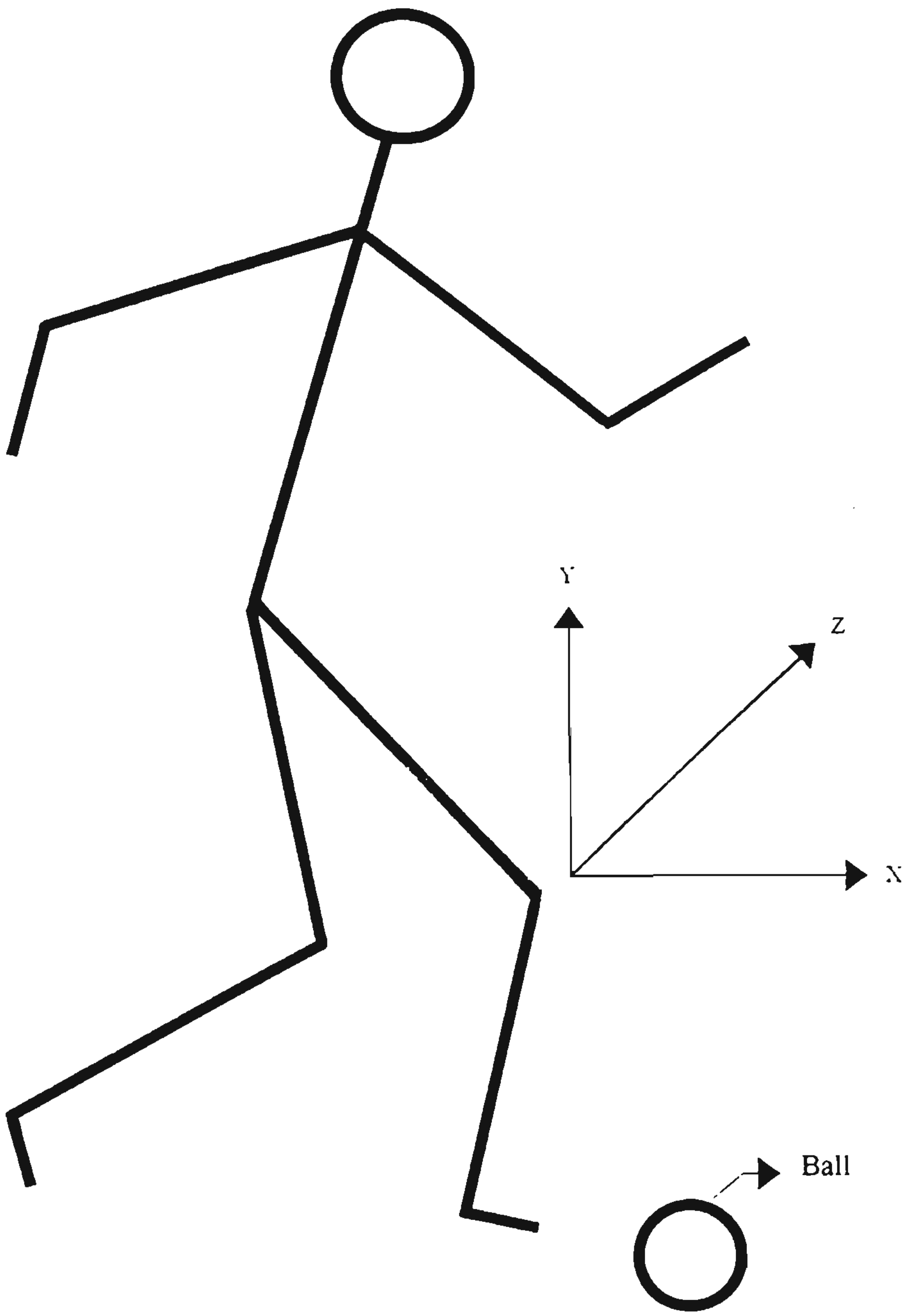


Figure 3.2.2.4.2 Motion Analysis Co-ordinate Specifications

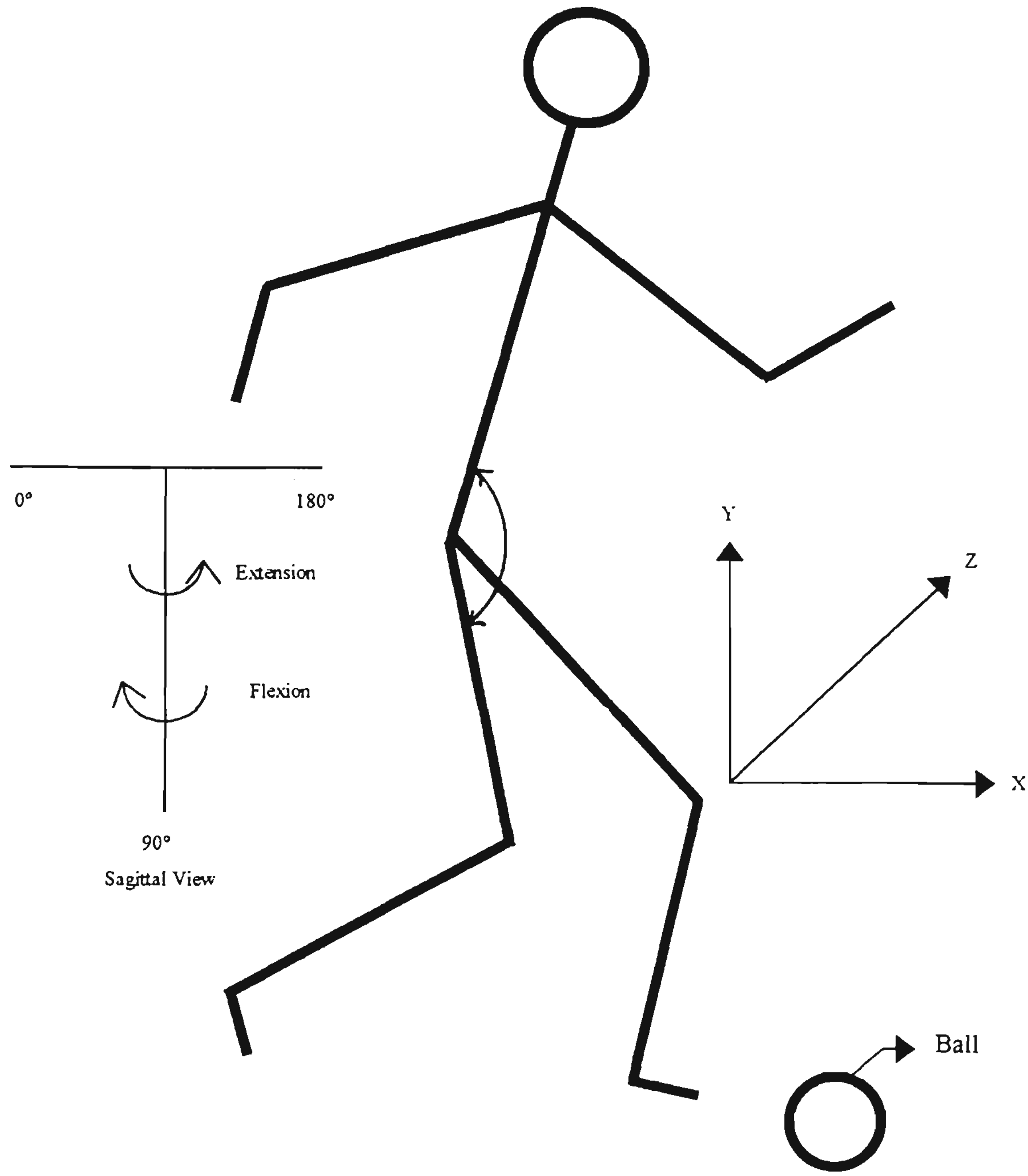


Figure 3.2.2.4.3 Reference Model for Hip Angle

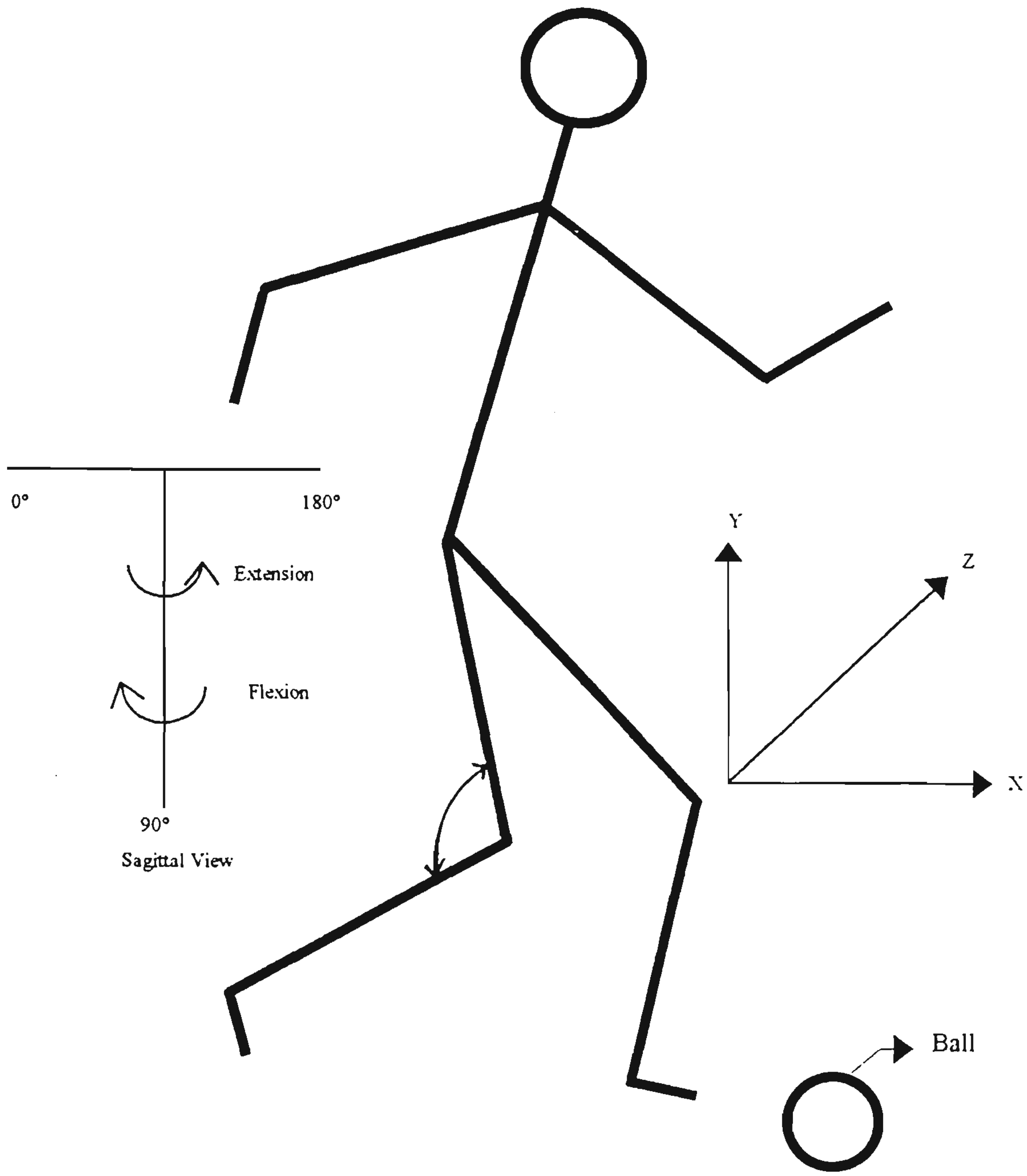


Figure 3.2.2.4.4 Reference Model for Knee Angle

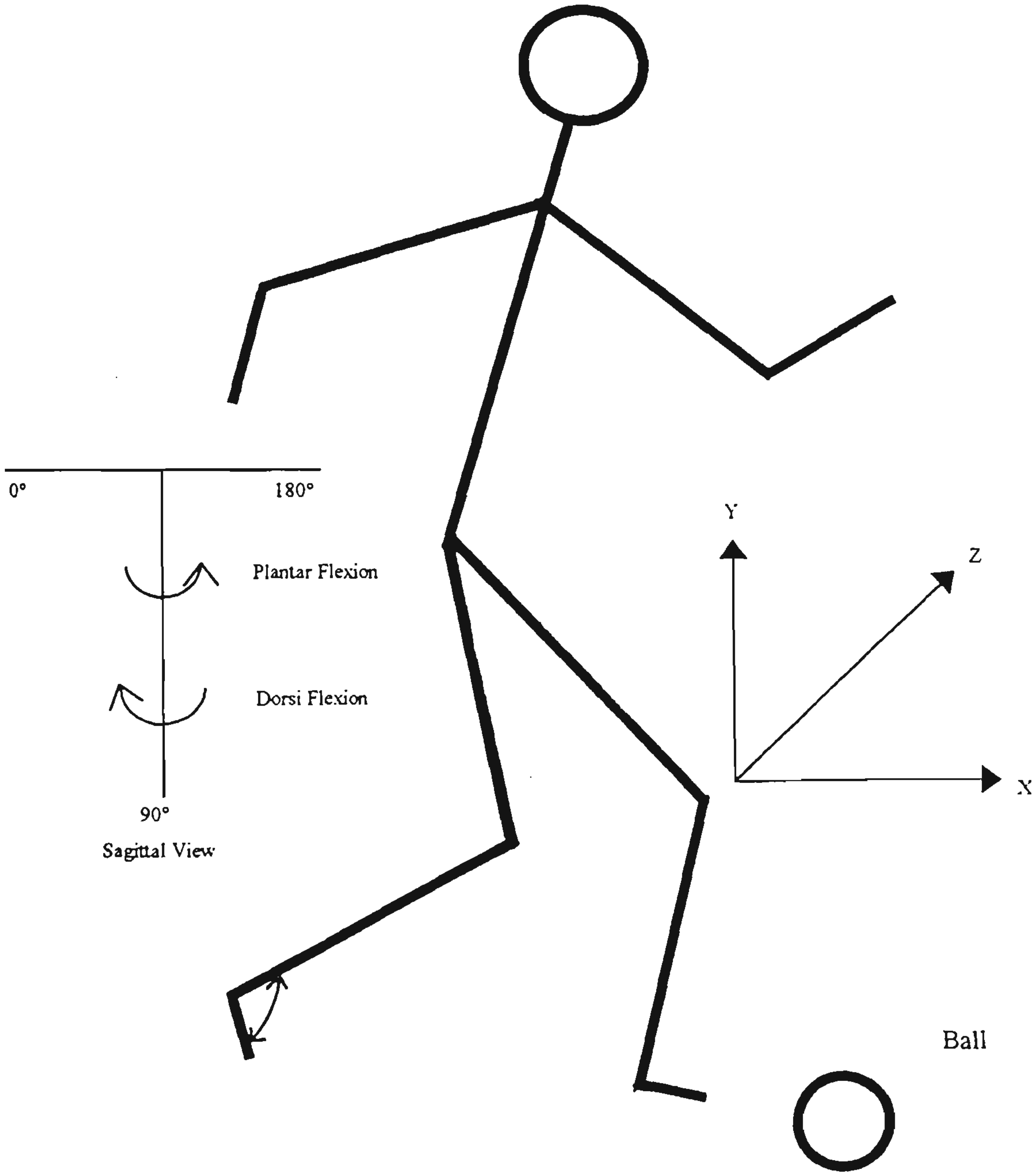


Figure 3.2.2.4.5 Reference Model for Ankle Angle

3.3.2 Application of the DLT Technique and Digitising of DLT Control Object

There are several methods to obtain three-dimensional co-ordinate data from multiple two-dimensional views as described in section 2.2. The DLT method, developed by Abdel-Aziz and Karara (1971) and further explained by Walton (1981) was used to reconstruct 3-D coordinates. The DLT method uses known co-ordinates in the object space of the calibration frame to determine the orientation of the image space of the video chips in the camera, with respect to the object reference frame. It also establishes a direct linear relationship between digitised co-ordinates from two or more camera views and the three-dimensional space co-ordinate by using intersections of lines or vectors from each camera view to determine the point in space.

The calibration frame (Figure 3.2.2.4.1) with control points was filmed simultaneously by both cameras. Each camera view of the DLT control object was digitised once to obtain X and Y co-ordinate for each control object point. All together 24 points of the DLT control objects were digitised. The origin was digitised at the beginning followed by the other points in sequence. The whole process of digitisation was carried out manually according to the procedure outlined in PEAK 3-D Motion Analysis System (PEAK 5 Mannual, 1993). Digitisations of all these 24 control points were done twice to calculate the average control point co-ordinates, which in turn reduces the error. Errors on all three directions were checked before actual digitisation (see section 3.6).

3.3.3 Digitising of the Instep Kick

Positional data of 19 joints centres/ body segments, centre of the ball and also two cones (for showing the direction of the kick) were digitised manually for each field of the recorded video from the two cameras views. In each field, all the 22 points were digitised before advancing to the next field. The joint centres/ points and body segments digitised were as follows: -

1. right wrist
2. right elbow
3. right shoulder
4. starnum
5. head
6. lumber vertebrae 5^{th}
7. right hip
8. right knee
9. right ankle
10. right heel
11. right toe
12. left shoulder
13. left elbow
14. left wrist
15. left hip
16. left knee
17. left ankle
18. left heel)
19. left toe
20. ball (centre)
21. cone (i)
22. cone (ii)

3.3.4 Smoothing of the Data

The Butterworth Digital Filter (PEAK 5 Mannual, 1993) permits to filter random amplitude noise that occurs during raw data collection. In order to filter out the digitising error of the digitised positional raw data of the joints centres/ body segments an optimal Butterworth Digital Filter was used. The PEAK System Software in this module of the programme using the Jackson Knee Method (PEAK 5 Manual, 1993) considered the optimal cut-off frequency for each data series. In this method first a curve is calculated with each filter parameter along the horizontal axis and percent average residual at each filter parameter along the vertical axis. Next, the second derivative of this curve is found at each filter parameter. Starting at zero filter parameter and working across the horizontal axis to the right, groups of three are sampled consecutively until a group of three second derivatives falls beneath a defined prescribed limit. The minimum filter parameter in this group is the optimal (PEAK 5 Manual, 1993). For all the data the optimal cut-off frequency was found to be below 10 Hz.

3.3.5 3-D Data and Parameter Calculation

The three-dimensional co-ordinates of the digitised joints centres/ segments and the centre of the ball were reconstructed from the two-dimensional smoothed data using DLT algorithm supplied by the PEAK System software. Velocities of smoothed displacement data were calculated using the following equation (PEAK 5 Manual, 1993): Given a time series of displacement data, d_i, i=1,....,n, where "d" is displacement data and "i" is an instant in time, linear/ angular velocity, "v_i", is calculated discretely using the following algorithm, where Δt is the time increment:

for i=1, forward difference:

$$v_i = (-d_{i+2} + 4d_{i+1} - 3d_i)/2\Delta t \quad ..... \quad (1)$$

for i=2,.....,n-1, second order central difference:

$$v_i = (d_{i+1} - d_{i-1}) / 2\Delta t \quad ..... \quad (2)$$

for i=n, backward difference:

$$v_i = (d_{i-2} - 4d_{i-1} + 3d_i) / 2\Delta t \quad ..... \quad (3)$$

The angular velocity was calculated using equations (1 – 3) and replacing linear displacement (d) by angular displacement (θ).

Centre of mass (COM) of an object is the point about which the mass of the object is evenly distributed (Winter, 1990; Enoka, 1994). In human movement, when limb segments are redistributed the location of COM also shifts. In order to determine the location of COM in such movements as in most of the sports activities, biomechanist have developed several procedure such as Reaction-Board Methods, Mannikin Methods and Segmentation Method etc. (Hay, 1993). In the present investigation the COM of the body was calculated using segmental method (Winter, 1990). In this method the COM is determined from the individual body segment mass (m_i) and location of segmental centre of mass (X_i, Y_i, and Z_i) from the axis of rotation. Thus for n-segment body system, the body COM in X direction can be given as:

$$X_{COM} = \frac{\sum_{i=1}^{n} X_i m_i}{\sum_{i=1}^{n} m_i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$\text{Where} \quad \sum_{i=1}^{n} m_i = M = \text{Body mass} \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

Similarly whole body COM in Y (Y_{COM}) and Z (Z_{COM}) directions can be obtained. The PEAK System software was used to calculate the body COM along X, Y and Z directions using anthropometric data from Dempster (1955) and 19 body segments/ points as shown in section 3.3.3. The COM velocities were determined using equations (1 – 3).

In order to investigate instep kick in soccer in terms of distance and accuracy various kinematic parameters were calculated from the re-constructed 3-D co-ordinates of joint centre and body segments. These include: Linear velocities of hip, knee, ankle, heel, toe, ball and the body COM along the direction of the target and Angular velocities of hip, knee and ankle joints.

3.5 STATISTICAL ANALYSIS

Kinematic parameters investigated throughout the different phases of kicking motion were represented with various plots and graphs using the SPSS and S-Plus computer software programs.

Inorder to test the tester's reliability in extracting the kinematic data Intraclass Coefficient of Correlation technique was applied (see section 3.6). The effect of different approach angles (0°, 15°, 30°, 45°, 60°, 75° and 90°) on human body kinematic variables that were calculated, maximum distance covered by the ball and the accuracy of the kick was determined by using Two Way Analysis of Variance (ANOVA). A Bonferroni post hoc test was applied in cases where "F" ratios were significant, to find-out which of the differences of the paired means were significant. For testing the hypothesis, the level of confidence was set at .05. Standard Multiple Regression Analysis Technique (Aron and Aron, 1994) at the .05 level of significance was applied in order to fit a relationship between the dependent variables and approach angle. In doing this following steps were taken:

- Subject effects were taken out by regressing the dependent variables against dummy variables representing the various subjects` in-order to account for the difference between the subjects.
- In spline curve fitting, the relationship is approximated by a piecewise, but smooth low-order polynomial. The wisest choice is a piecewise cubic polynomial (Fox and Long, 1990). Therefore cubic spline method was applied in the present investigation. A cubic spline with a knot at 45° was fitted to the residuals from the

above regression. "F" test was conducted to examine whether a cubic spline gave a better fit than merely a cubic polynomial. The cubic spline equation with a knot at AA=45° is given by

$$\begin{aligned} DCB\,(Y) = \beta_0 \quad &+ \quad \beta_1\,(AA - 45) \\ &+ \quad \beta_2\,(AA - 45)^2 \\ &+ \quad \beta_3\,(AA - 45)^3 \\ &+ \quad \beta_4\,(AA - 45)^3_+ \quad \ldots\ldots\ldots\ldots(6) \end{aligned}$$

Where β = coefficients and $(AA\text{-}45)_+ = (AA\text{-}45)$ for $AA > 45$ and "0" elsewhere.

If $\beta_4 = 0$ the cubic spline reduces to a cubic polynomial. A test for whether the cubic spline gives a better fit than a cubic polynomial was conducted by following both models and comparing the residual sum of square (SS) using:

$$F = \frac{SS\,(\text{Cubic Polynomial}) - SS\,(\text{Cubic Spline})}{SS\,(\text{Cubic Spline})/df}$$

which has a central "F" distribution under the null hypothesis that $\beta_4 = 0$.

- The plot and fitted spline (as shown in result section) is given in the figure adding back the overall mean value, to make the vertical axis more appropriate.

The effect of body kinematic variables (linear velocities of hip, knee, ankle, heel, toe, COM and angular velocities of hip angle, knee angle and ankle angle) on maximum distance covered by the ball at difference approach angles were determined by step wise regression equation entering subject dummy variables, angle and angle^2. This was done in order to determine which of the kinematic variables also had an effect on the DCB additional to that of subject and approach angle. Following this a full quadratic model was fitted involving the significant kinematic variables from the analysis above and AA versus DCB.

3.6 ACCURACY AND RELIABILITY TESTING OF KINEMATIC DATA

To ensure that the investigator was well versed with the technique of conducting the tests, the investigator had a number of practice sessions in the testing procedure under the guidance of an expert.

In order to test the 3-D reconstruction, the PEAK system's software was used to compare the known 3-D locations of calibration markers with their reconstructed positions. The average mean square error for the 24 control points were found to be: 0.6 cm (X), 0.2cm (Y) and 0.6 cm (Z). The errors found in the present study were comparable to those reported by other investigators (Shapiro, 1978; Miller, Shapiro and McLaughlin, 1980; Wood and Marshall, 1986 and Tant, 1990).

Tester reliability in extracting the kinematic data were established by the test-retest process whereby consistency of results were obtained by Intraclass Coefficient of Correlation (ICC) as refered by Vincent (1995). The data collected from a random selection of one subject in test was computed for the selected kinematic variables and obtained ICC have been shown in Table 3.1.6.1.

Table 3.1.6.1 Tester Competency in Selected Kinematic Variables

Kinematic Variable	SEM	ICC
Linear Velocity of Hip	0.07	0.97
Linear Velocity of Knee	0.07	0.97
Linear Velocity of Ankle	0.12	0.95
Linear Velocity of Heel	0.11	0.93
Linear Velocity of Toe	0.25	0.92
Angular Velocity of Hip	10.84	0.91
Angular Velocity of Knee	10.71	0.99
Angular Velocity of Ankle	9.33	0.99
Body Centre of Mass	0.12	0.91

The ICC of the subject across the digitisation of the kinematic data were in between 0.91 to 0.99 (Table 3.1.6.1). For a physiological data the ICC value above 0.90 are considered high, from 0.80 to 0.89 moderate and below 0.80 questionable (Vincent, 1995). Since the obtained ICC in the present investigation were above 0.90, the kinematic data can be considered to be highly repeatable.

Chapter iv

RESULTS

The purpose of this investigation was to analyse the three-dimensional motion of selected biomechanical parameters of the lower extremity during kicking. The results of the present investigation are organised under the following headings:

(a) Description of the subject

(b) Kinematic description of instep kick motion

(c) Effect of approach angles on distance covered by the ball

(d) Effect of approach angles on accuracy of the kick

(e) Analysis of kinematic variables

(f) Examination of hypothesis

(g) Summary of hypothesis

4.1 DESCRIPTION OF THE SUBJECT

Twenty male soccer players of the State Soccer League-Division Four, Victoria acted as subjects for the study. Table 4.1.1 presents the demographic data of all the subjects participated in the investigation.

Table 4.1.1 Demographic Profile of the Subjects

Variable	N	Range (Min -Max)	M	SD
Age (years)	20	5.70 (19.30-25.00)	22.28	1.75
Years of playing	20	4.00 (11.00-15.00)	12.30	1.34
Body mass (kg)	20	12.00 (62.00-74.00)	68.52	3.60
Stature (cm)	20	10.00 (165.00-175.00)	171.4	2.34

Table 4.1.1 demonstrates that a relatively homogeneous group participated in the study, as evidenced by the small standard deviations. The difference between the subject's age and years of playing, which is about 10 year indicates that they have started playing soccer fairly at an early age. Demographic profiles particularly stature and body mass presented in earlier studies (DeProft, et al., 1988; Narci, et al., 1988; Tant, 1990) are comparable to the present study. Basic anthropometric measurements of the subjects presented in Table 4.1.2 also show that the subjects were relatively homogeneous with low standard deviation for these variables.

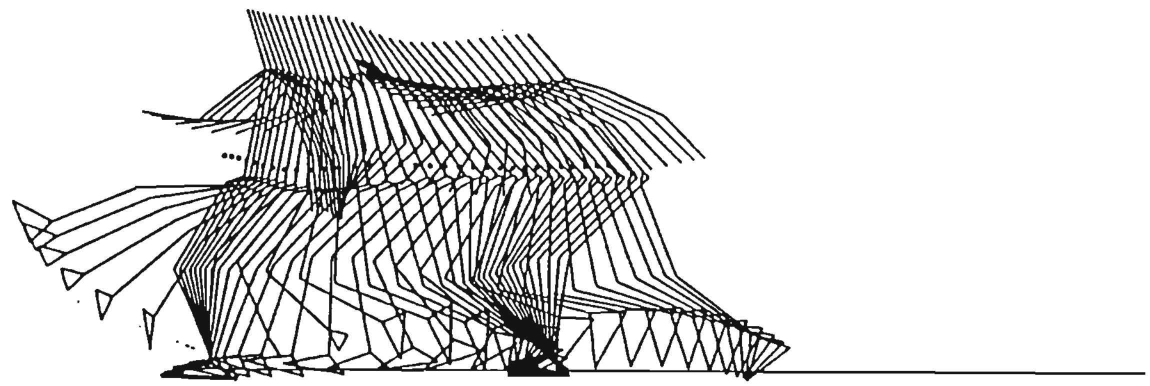
Table 4.1.2 Anthropometric Data of the Subject

Variable	Range (Min - Max)	M	SD
Thigh Length (cm)	6.70 (36.5-43.2)	40.61	1.70
Leg Length (cm)	6.60 (46.3-39.7)	42.81	1.73
Ankle Height (cm)	1.60 (8.5-6.9)	7.34	0.35
Leg Length (cm	10 (165-175)	90.76	3.57

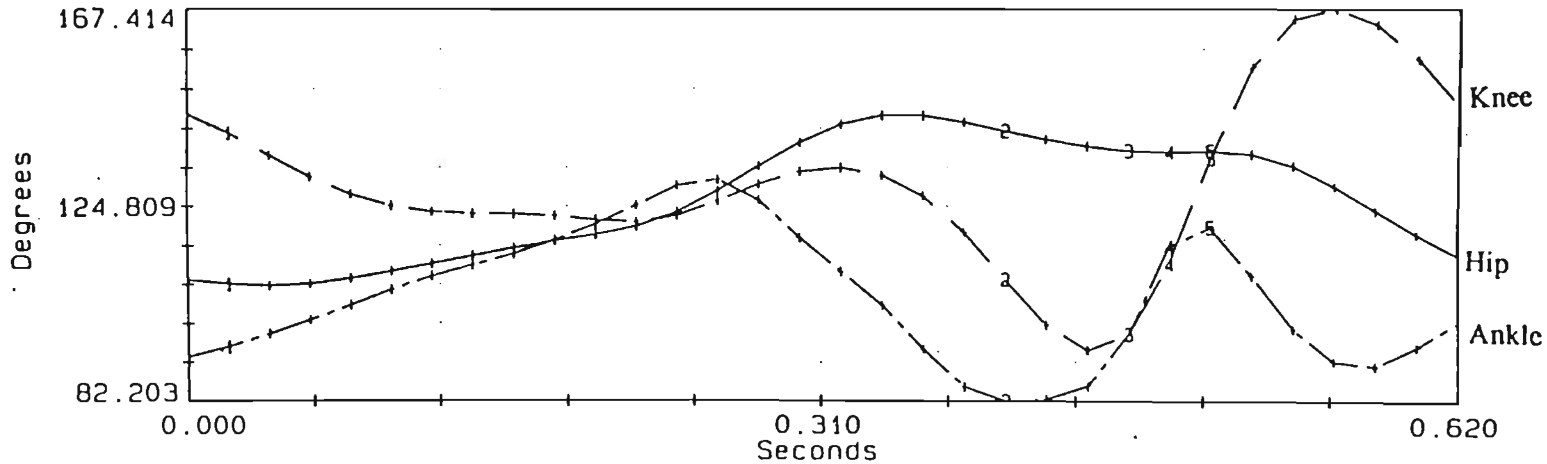
4.2 KINEMATIC DESCRIPTION OF INSTEP KICK MOTION

In order to describe the kinematics of instep kick motion, the data of a typical subject was abstracted. The whole motion of the instep kick was described on the basis of the angular motion of the lower limb joints. Particularly angular displacement and angular velocity data of the hip, knee and ankle joints of the kicking limb were considered. These data were presented during the following main phases/ events: (a) Approach phase (ground contact of the kicking foot to ground contact of the non-kicking foot); (b) Pre-Impact (ground contact of the non-kicking foot to before contact of ball with the kicking foot); (c) Impact/ Ball Contact (ball contact with kicking foot) and (d) Follow-through (ball contact to ball take-off).

The depicted angular displacement data are presented in the Figures 4.2.1. - 4.2.7 revealed no major differences in the pattern of the hip angle displacement, while kicks were taken from the different approach angles. During the approach phase of the kick initially hip extended from the beginning of the kick and attained maximum extension prior to non-kicking foot contact with the ground (NKFC) in all the approach angles. The approach angle (AA) of 90° yielded a maximum extension of the hip of about 161°. The moment it reached the maximum extension thereafter it followed the gradual flexion through to other phases of the kick (pre-impact, impact and follow-through) and attained maximum when it passes through the follow-through phase. The highest flexion of the hip was also observed while kick was executed from the approach angle of 90°.

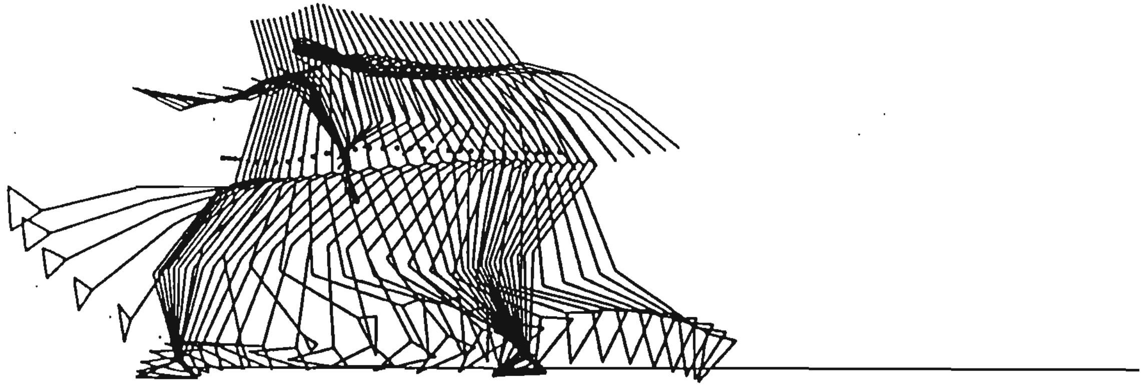


Stick Figure of Instep Kick Motion

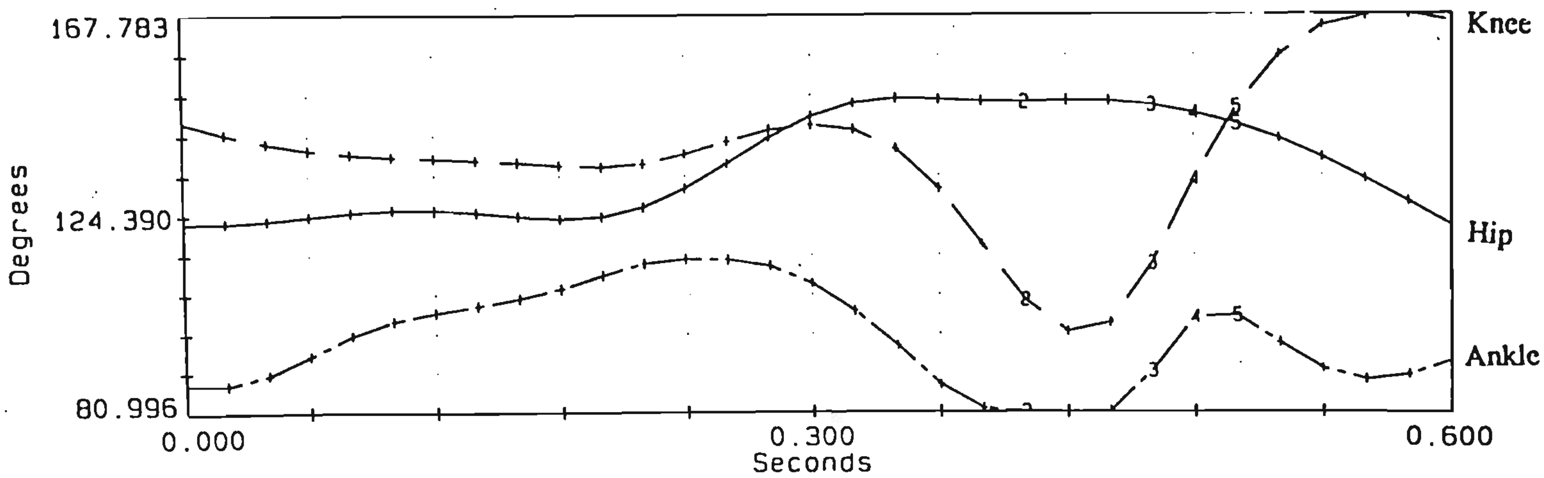


1 = Kicking foot contact with ground
2 = Non-kicking foot contact with ground
3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot
5 = Ball take-off

Figure 4.2.1 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (0° Approach)

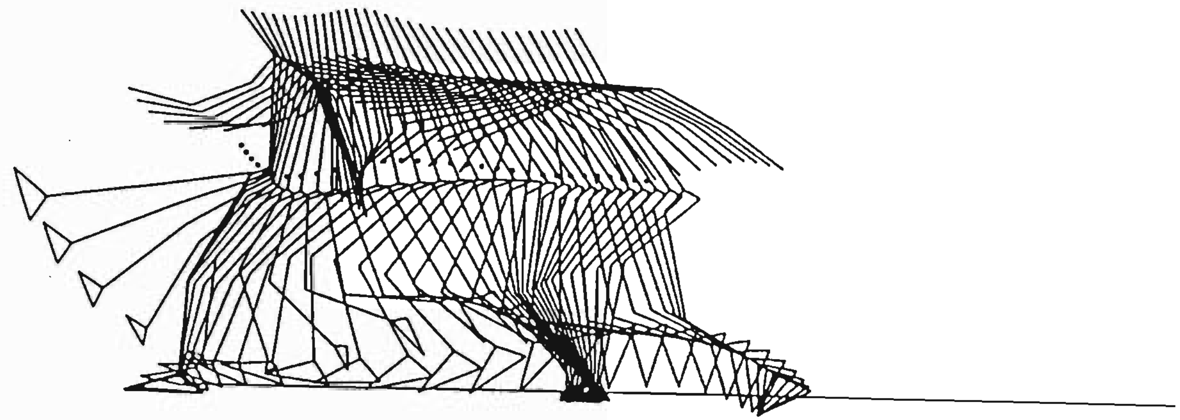


Stick Figure of Instep Kick Motion

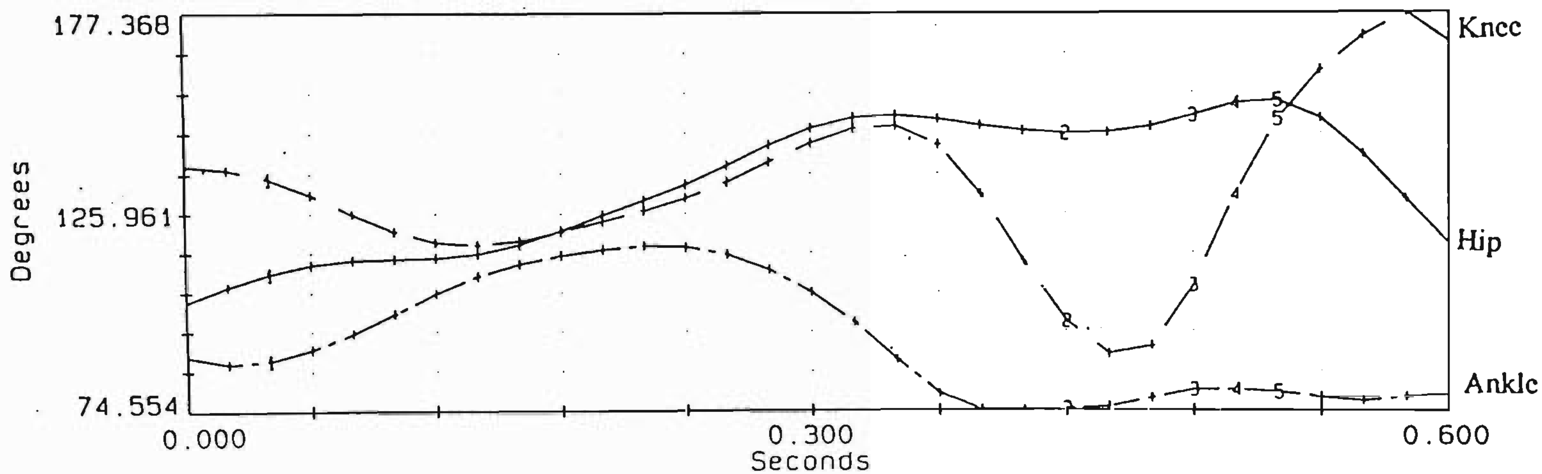


1 = Kicking foot contact with ground
2 = Non-kicking foot contact with ground
3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot
5 = Ball take-off

Figure 4.2.2 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (15° Approach)

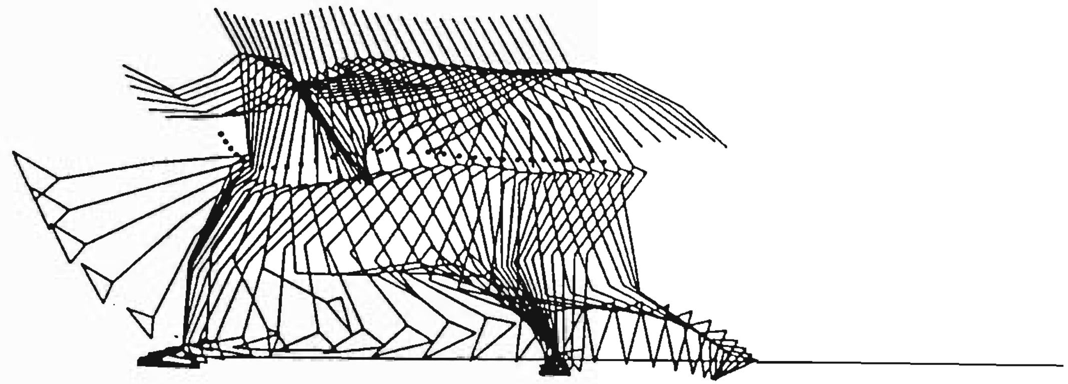


Stick Figure of Instep Kick Motion

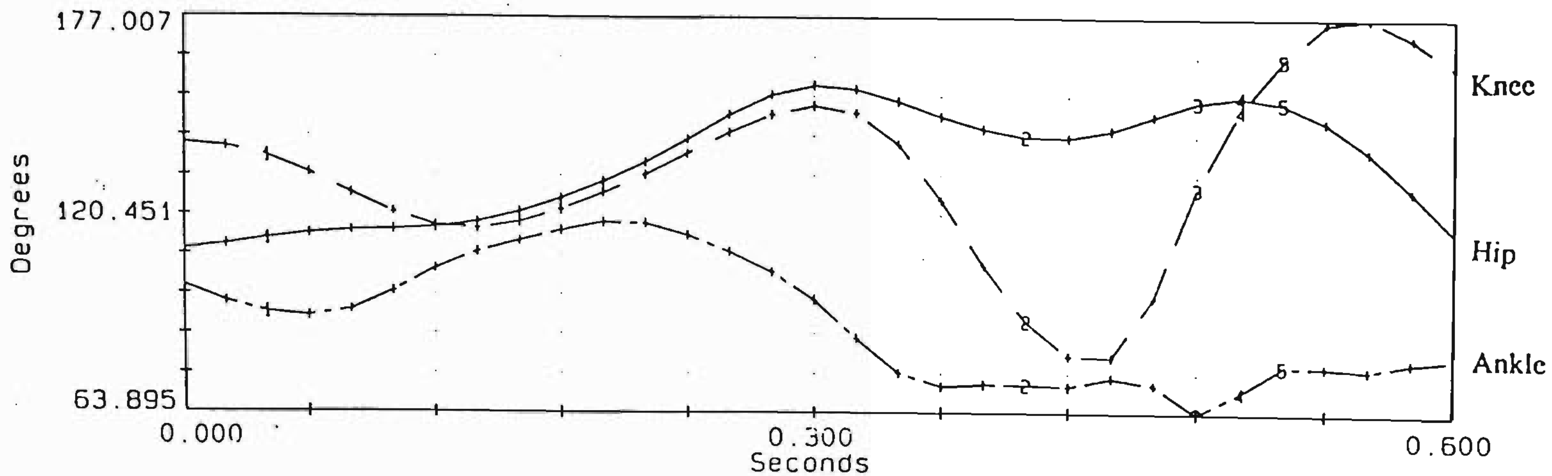


1 = Kicking foot contact with ground   2 = Non-kicking foot contact with ground   3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot   5 = Ball take-off

Figure 4.2.3 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (30° Approach)

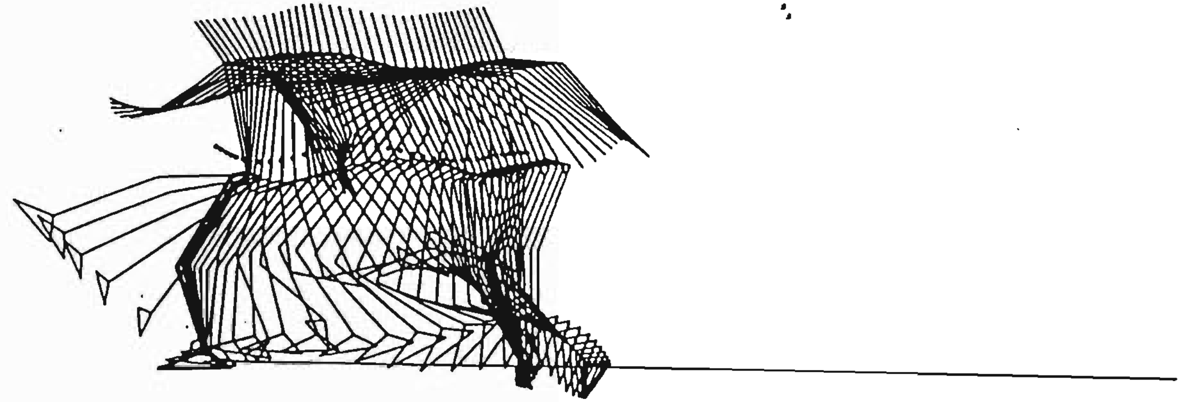


Stick Figure of Instep Kick Motion

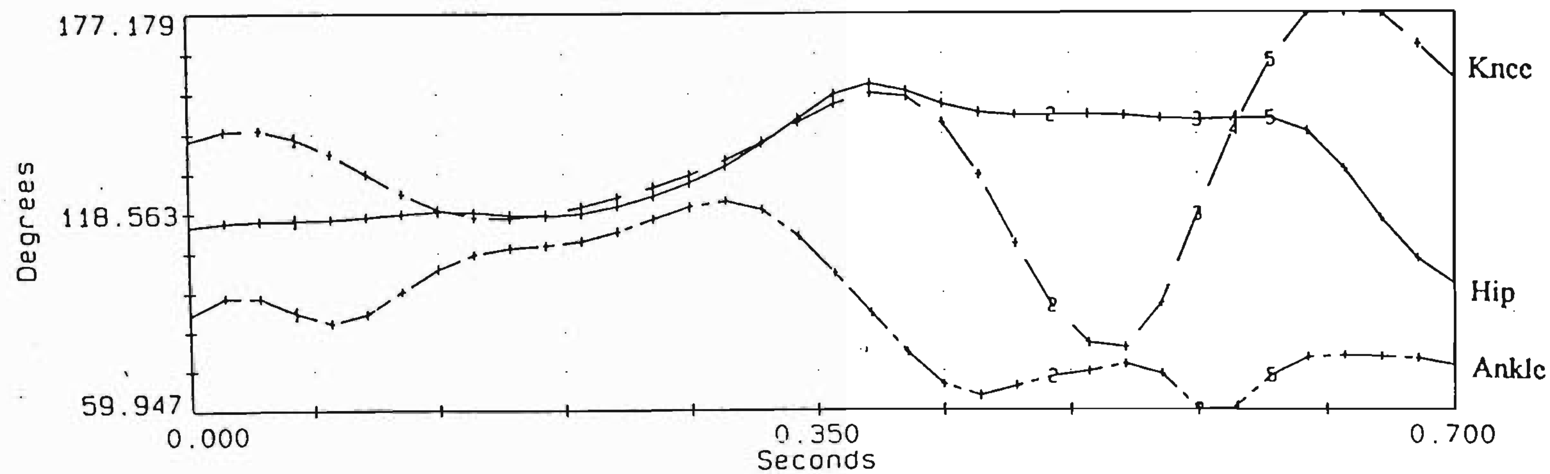


1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.4 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (45° Approach)

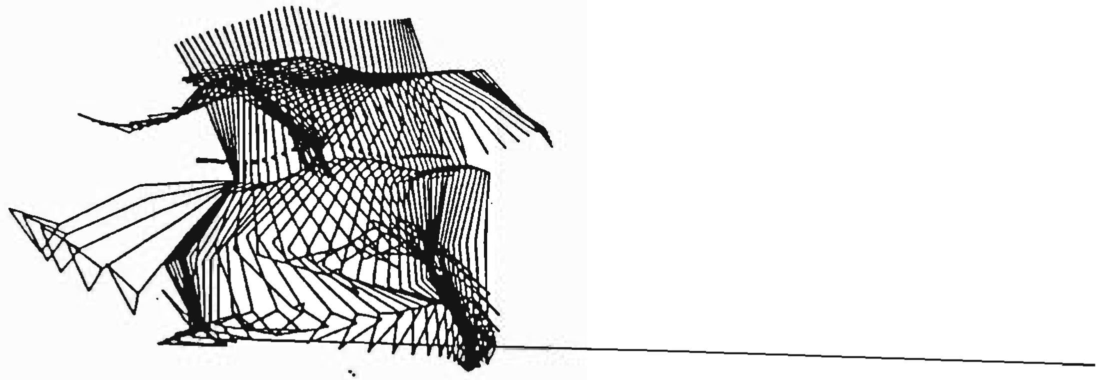


Stick Figure of Instep Kick Motion

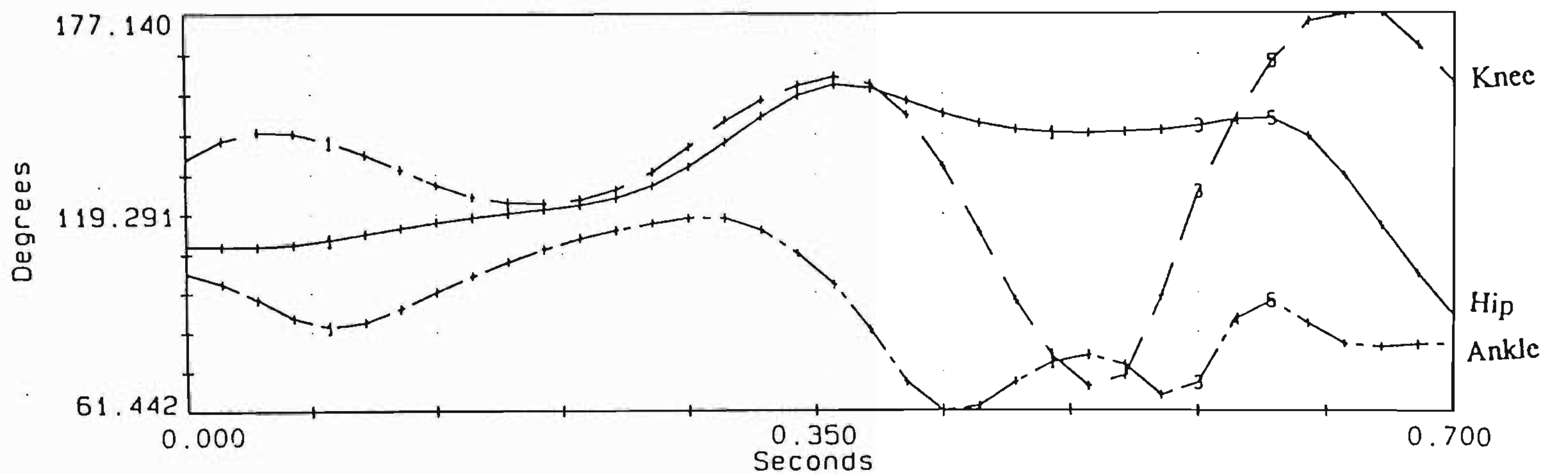


1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.5 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (60° Approach)



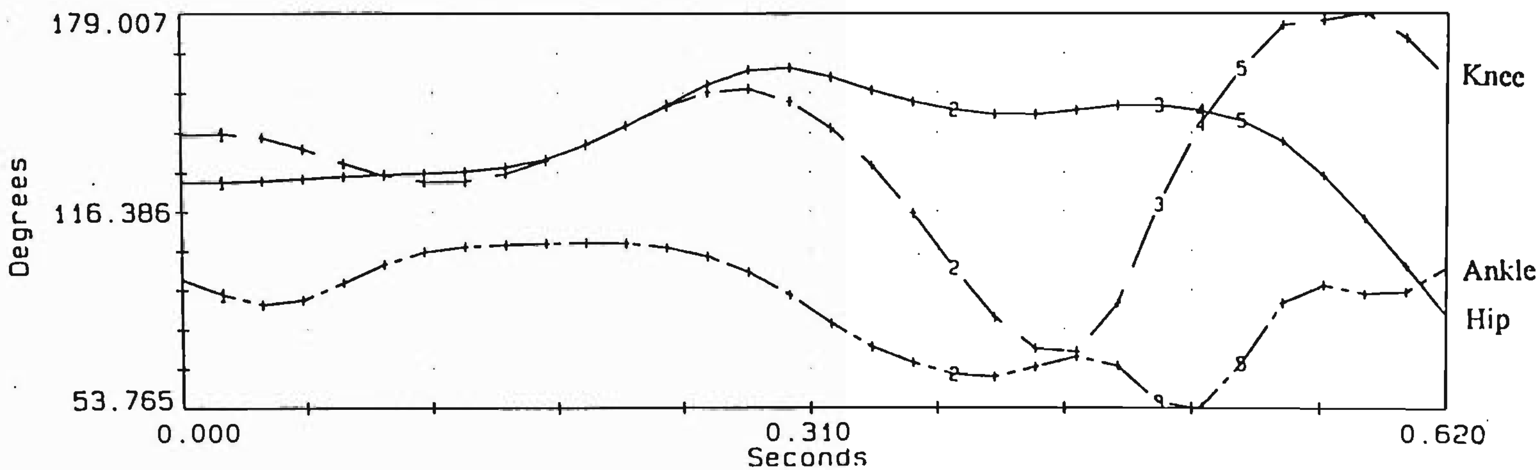
Stick Figure of Instep Kick Motion



1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.6 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (75° Approach)

Stick Figure of Instep Kick Motion



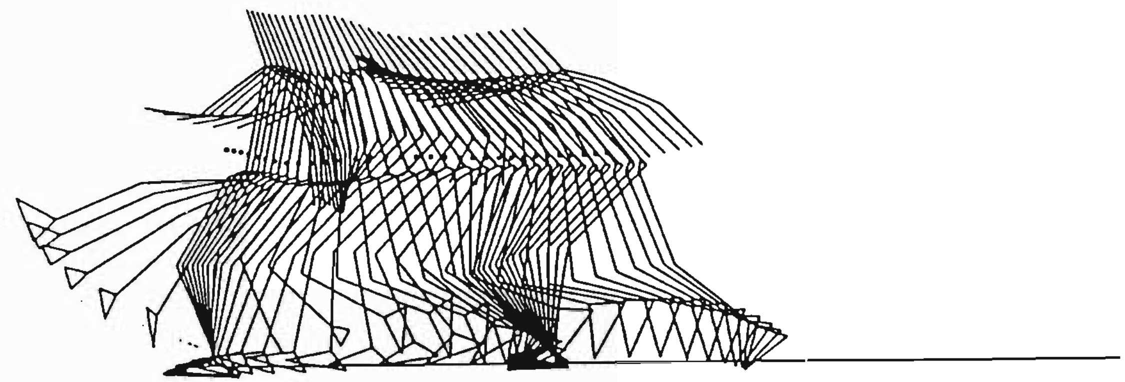
1 = Kicking foot contact with ground　2 = Non-kicking foot contact with ground　3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot　5 = Ball take-off

Figure 4.2.7 A Representative Trial Showing Stick Figure Diagram and Angular Displacement of Hip, Knee and Ankle Joints (90° Approach)

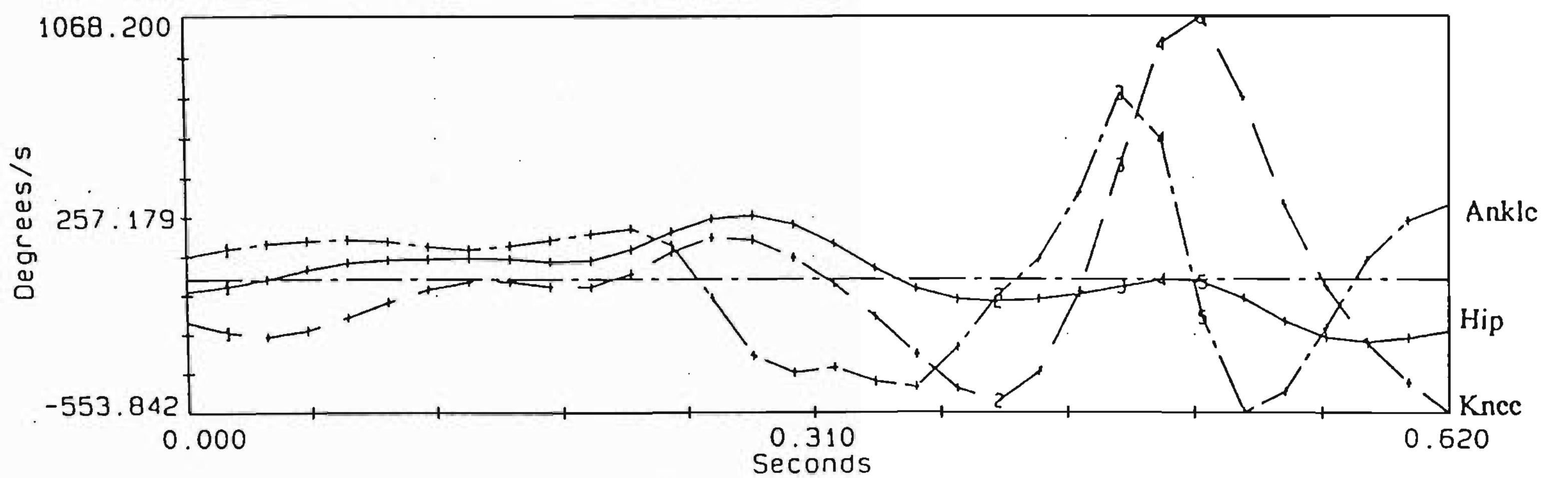
The displacement of the knee angle (see Figures 4.2.1. - 4.2.7) followed similar pattern in all the kicks taken from different AA. During the approach phase knee began to flex and then extended and then again flexed, until it reached maximum prior to pre-impact phase (BBC) of the kick. For this subject, the AA of 75° produced the maximum flexion of the knee (69°). The maximum extension of the knee was found after it passed through the phase of follow-through after BC. The knee attained full extension for 90° AA.

The ankle joint underwent initially plantarflexion followed by dorsiflexion movement in the approach phase of kicking motion. This was observed for all the kicks taken from the different AA (see Figure 4.2.1 - 4.2.7). During the approach phase the maximum and minimum plantarflexion of the ankle was noted while kicks were taken form the AA of 0° (130°) and 90° (106°) respectively. As the motion of the kick passed through the approach phase the ankle once again began plantarflexing until it reached follow-through phase and then tilted back to dorsiflexion. This trend of angular motion was observed in the kicks taken from most of the approach angles (0° to 75°). The maximum and minimum dorsiflexion of the ankle during the approach phase was observed while kick was taken from the AA of 90° (53°) and 0° (82°) respectively.

The relevant angular velocity data (hip, knee and ankle) of the kicking limb has been displayed in Figures 4.2.8 - 4.2.14. The angular velocity of the hip was recorded maximum while kicks were executed from the AA of 60° (365 deg/s) followed by 75° (356 deg/s) and 45° (339 deg/s). These angular velocities were generated while hip was extended to its maximum during the approach phase of the kick. Interesting to note that

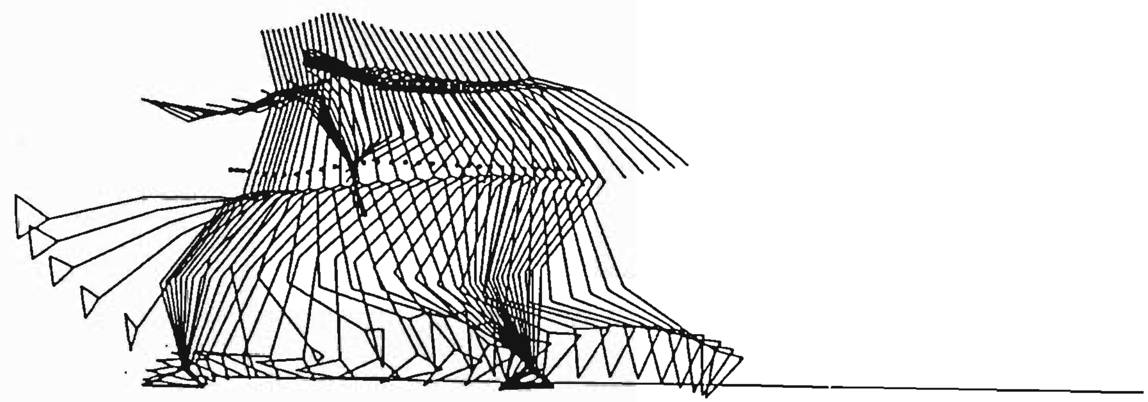


Stick Figure of Instep Kick Motion

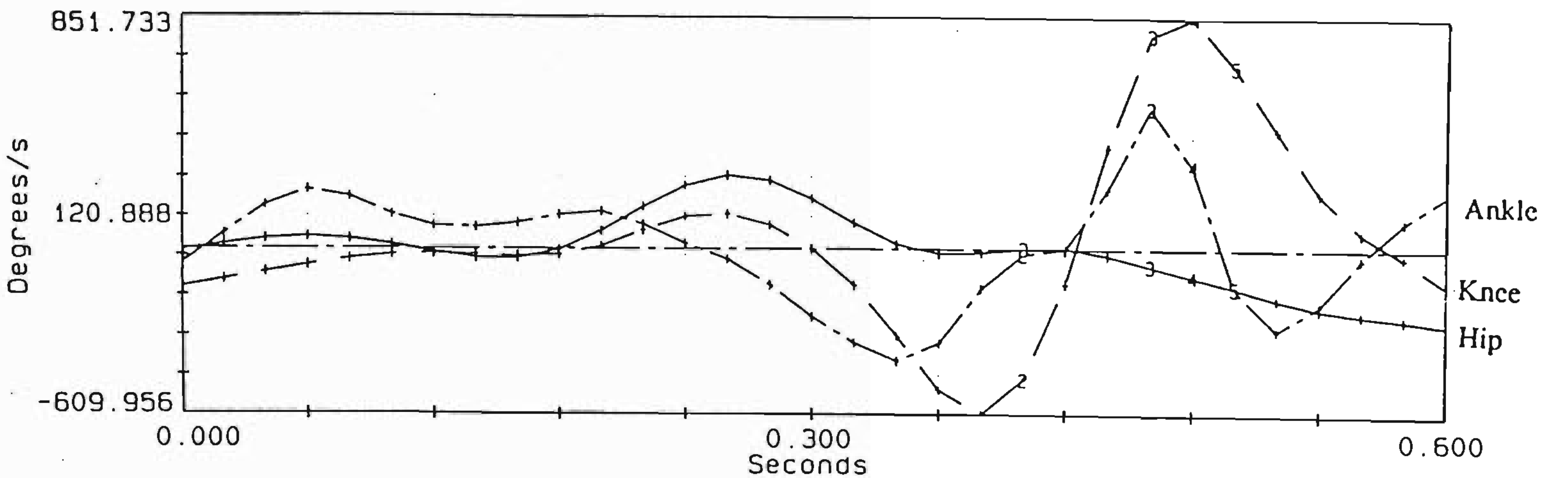


1 = Kicking foot contact with ground
4 = Ball contact of kicking foot
2 = Non-kicking foot contact with ground
5 = Ball take-off
3 = Before ball contact of kicking foot

Figure 4.2.8 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (0° Approach)

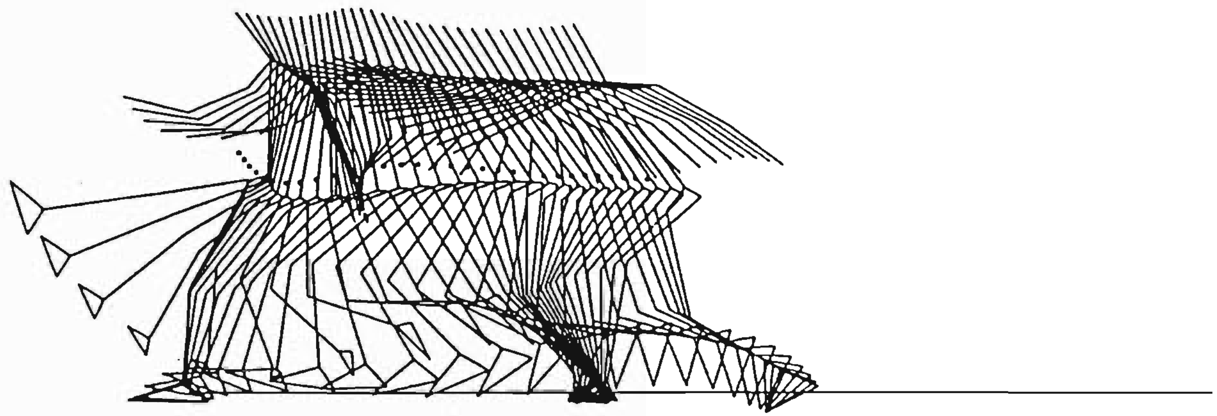


Stick Figure of Instep Kick Motion

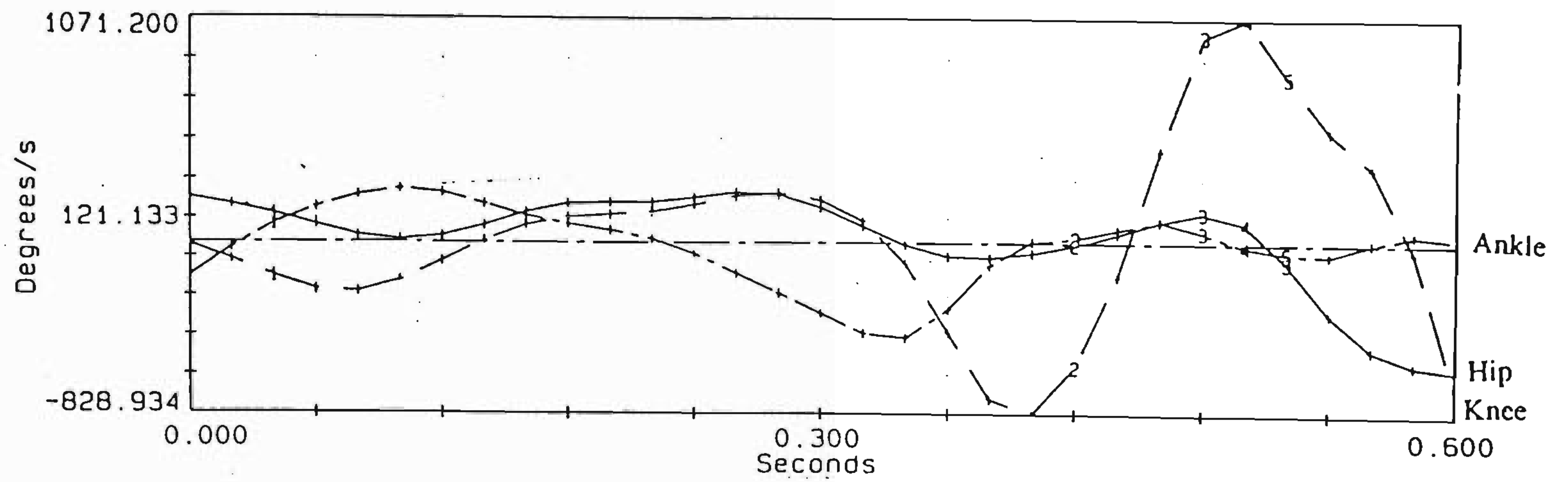


1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.9 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (15° Approach)

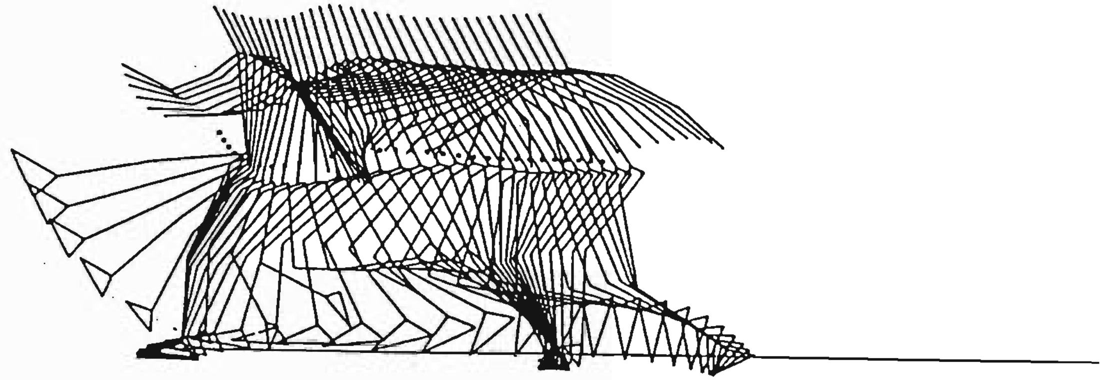


Stick Figure of Instep Kick Motion

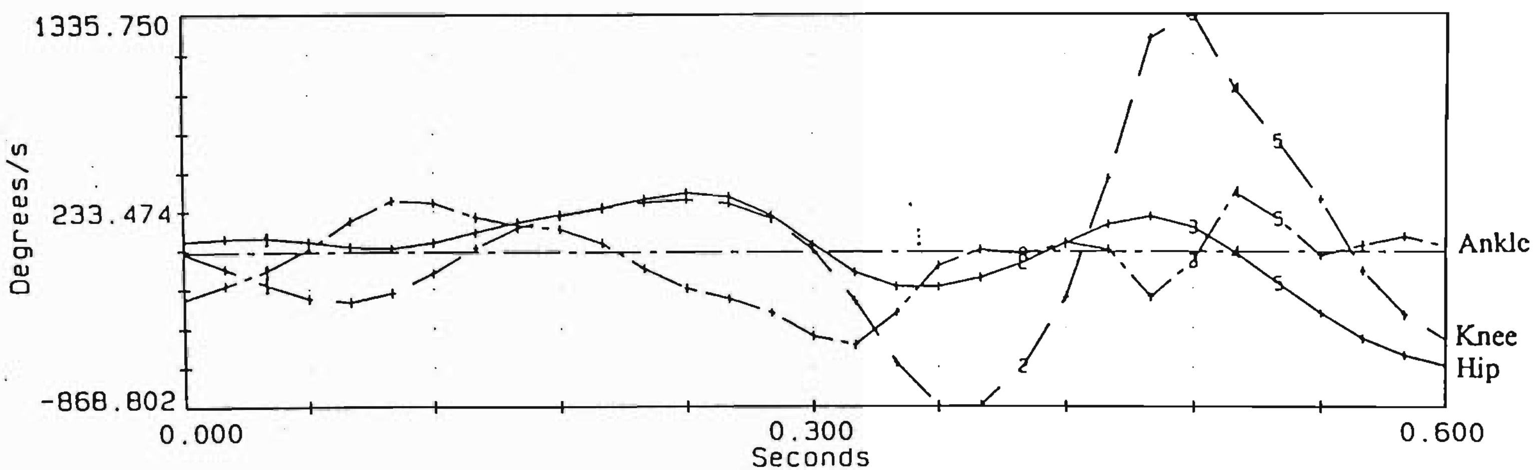


1 = Kicking foot contact with ground
2 = Non-kicking foot contact with ground
3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot
5 = Ball take-off

Figure 4.2.10 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (30° Approach)

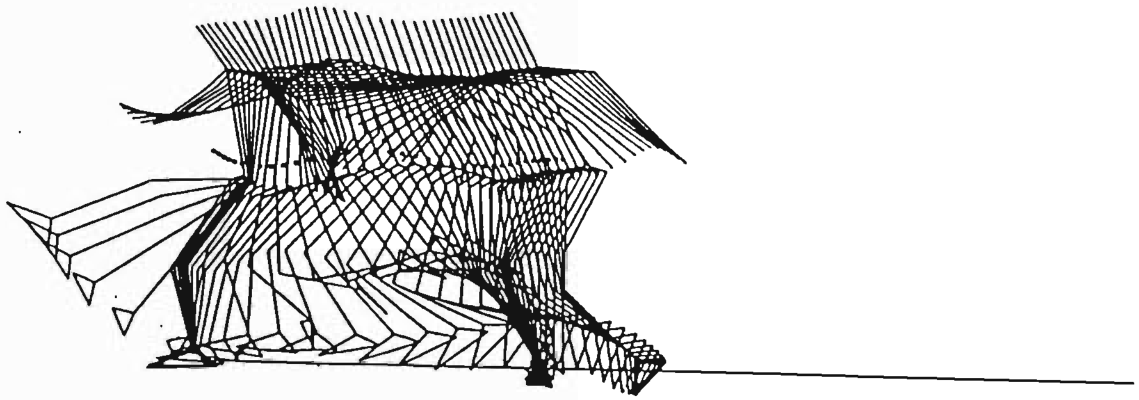


Stick Figure of Instep Kick Motion

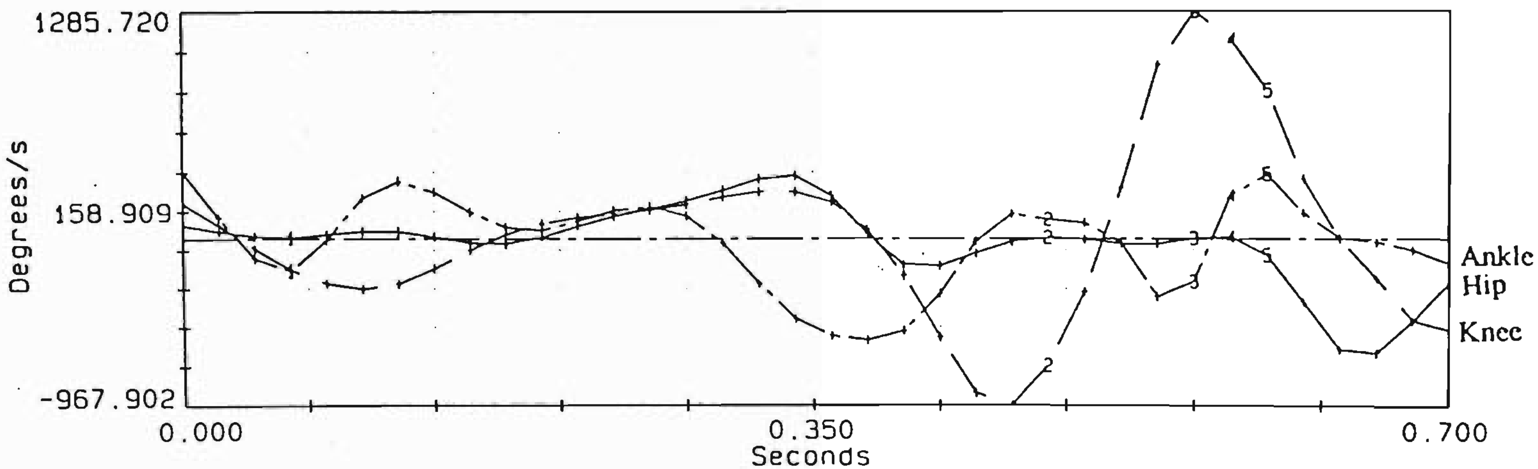


1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.11 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (45° Approach)

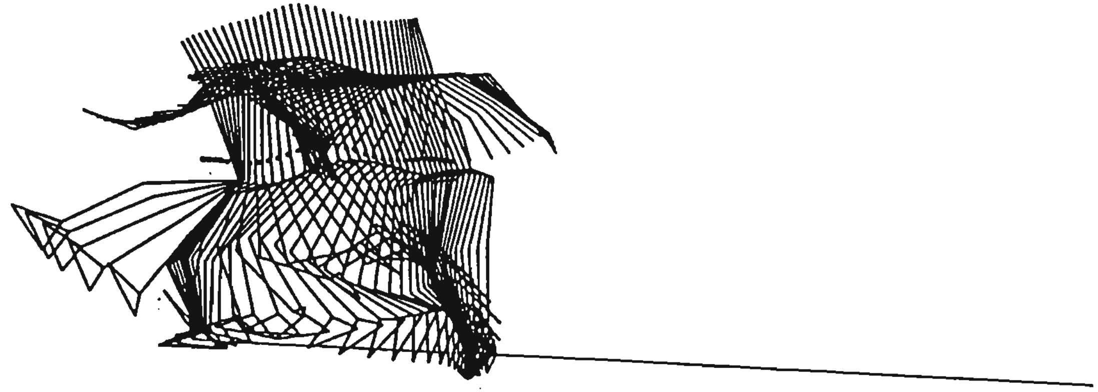


Stick Figure of Instep Kick Motion

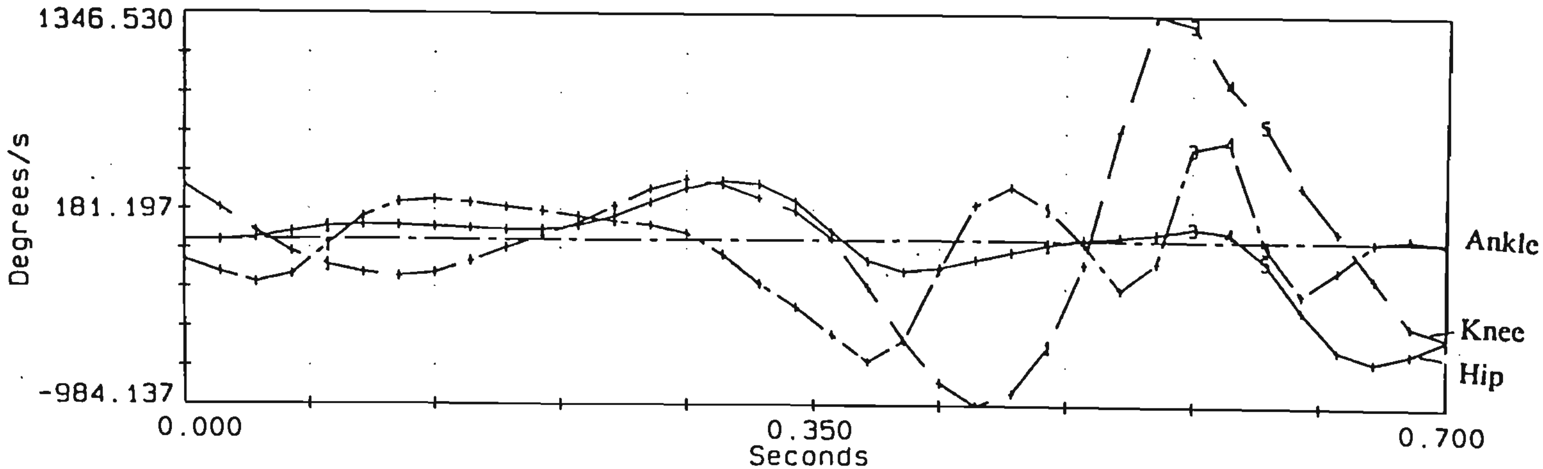


1 = Kicking foot contact with ground
2 = Non-kicking foot contact with ground
3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot
5 = Ball take-off

Figure 4.2.12 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (60° Approach)

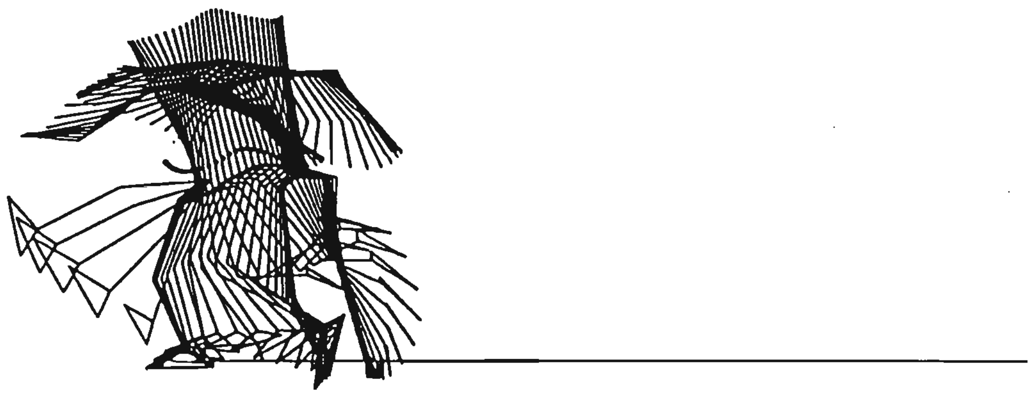


Stick Figure of Instep Kick Motion

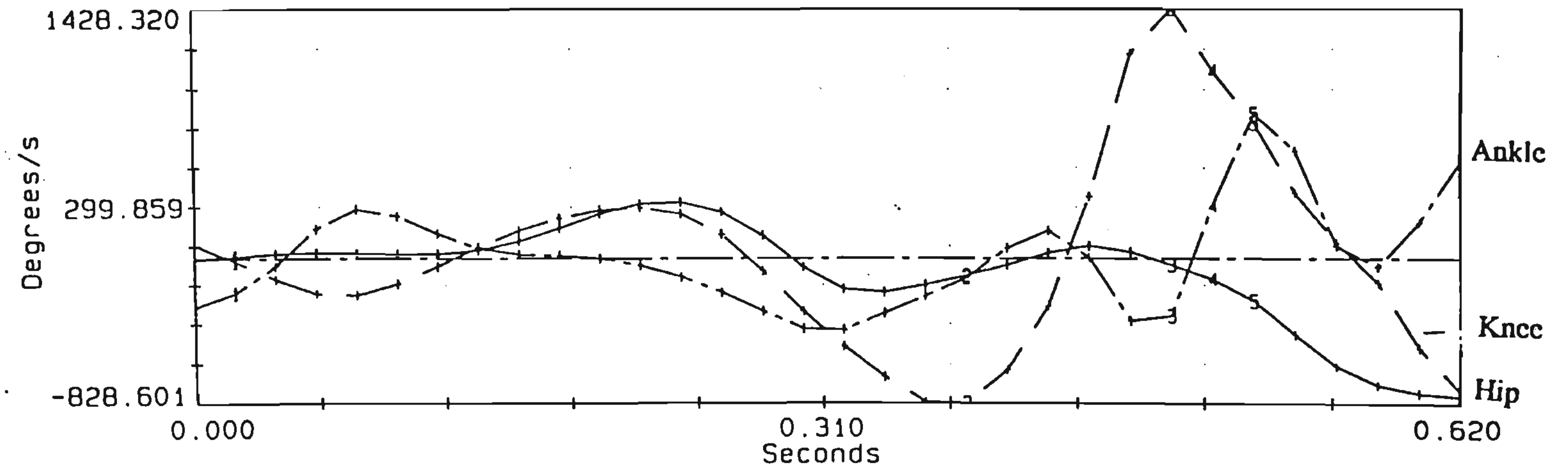


1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.13 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (75° Approach)



Stick Figure of Instep Kick Motion



1 = Kicking foot contact with ground 2 = Non-kicking foot contact with ground 3 = Before ball contact of kicking foot
4 = Ball contact of kicking foot 5 = Ball take-off

Figure 4.2.14 A Representative Trial Showing Stick Figure Diagram and Angular Velocity of Hip, Knee and Ankle Joints (90° Approach)

the angular velocity of the knee attained maximum at impact phase (BC) for the AA of 15° (Figure 4.2.9) and 30° (Figure 4.2.10). For the AA of 45°, 60° and 90° the maximum angular velocities were yielded at pre-impact phase (BBC). For this subject 0° AA showed maximum knee angular velocity at follow-through phase (BTO) and 75° AA during the approach phase. It was however evident from the Figure 4.2.14 that 90° AA produced maximum velocity (1428 deg/s). The maximum angular velocity of the ankle for this subject was found for an AA of 90° (835 deg/s) at follow-through phase (BTO) and minimum for 30° (263 deg/s) AA during the approach phase.

4.3 EFFECT OF APPROACH ANGLES ON DISTANCE COVERED BY BALL

Table 4.3.1 summarised the descriptive statistical values of maximum distance covered by the ball at different approach angles. Figure 4.3.1 shows the effect of the different approach angles (AA) on distance covered by the ball (DCB) adjusted for subject differences as described in section 3.5. From the figure it is evident that the fit was quite good with a r-square value of .79. Part of the two way ANOVA table presented in Table 4.3.2 revealed that there was a significant effect of AA on DCB ($F= 77.42$; $p< .0001$). The optimum distance covered by the ball was found while kicks were taken from the AA of 30° - 60°. The AA of 45° produced the maximum DCB (M=39.01m) among all followed by 60° (M=36.42m), 30°(M=35.67m), 75°(M=33.68m), 15°(32.89m), 90°(M=30.65m) and 0°(M= 28.92 m). The result of Bonferroni Post Hoc Test (see Appendix D Table 1) revealed that 0°, 45° and 90° AA were significantly different from the rest of AA, in terms of DCB. 15° AA showed significant differences from 30° and 60° AA.

Table 4.3.1 Descriptive Statistics of Distance Covered by the Ball at BC

Approach Angle	Range (Min - Max)	M (m)	SD (m)
0°	12.86 (21.66-34.52)	28.92	3.40
15°	15.96 (24.7-40.66)	32.89	3.96
30°	13.05 (29.5-42.55)	35.67	4.00
45°	14.86 (31.0-45.86)	39.01	4.80
60°	13.65 (28.7-42.35)	36.42	4.31
75°	14.8 (25.3-40.10)	33.68	4.41
90°	16.1 (22.8-38.90)	30.65	4.17

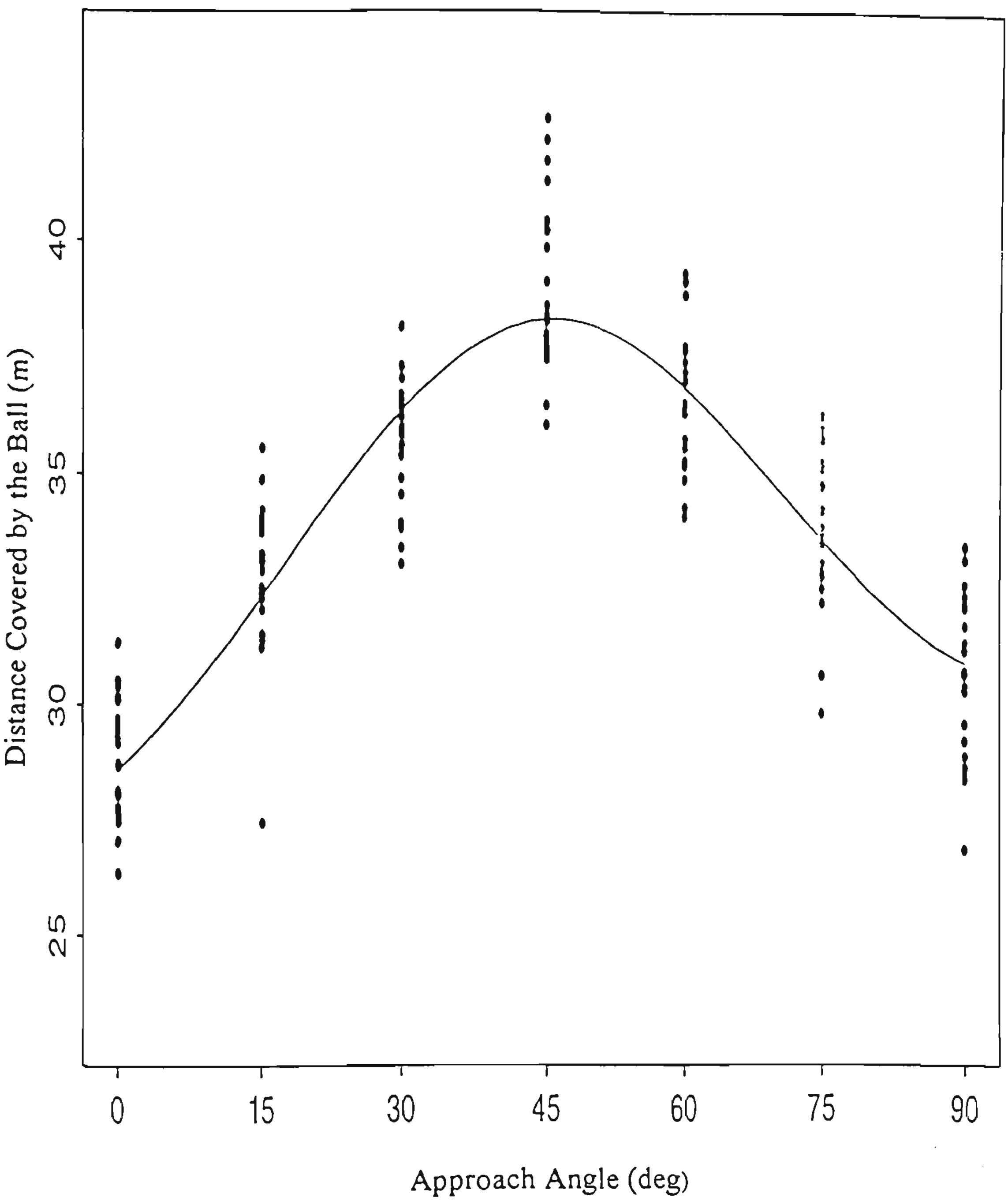


Figure 4.3.1 Effect of Approach Angle on Distance Covered by the Ball

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.89$, $r^2 = 0.78$

$$\beta_0 = 38.32$$
$$\beta_1 = 1.56 \times 10^{-2}$$
$$\beta_2 = -9.36 \times 10^{-3}$$
$$\beta_3 = -1.14 \times 10^{-4}$$
$$\beta_{3+} = 2.30 \times 10^{-4}$$

Table 4.3.2 Test for Differences Between Group from Two-way Analysis of Variance

Variable	Source	df	Sum of Squares	Mean Square	F	p
DCB	B	6	1441.40	240.23	77.42	0.0001*
	W:	114	353.75	3.10		
AC	B:	6	154.92	25.82	79.63	0.0001*
	W:	114	36.96	0.32		
LVH	B:	6	30.32	5.05	61.62	0.0001*
	W:	114	9.42	0.08		
LVK	B:	6	9.08	1.51	7.92	0.0001*
	W:	114	21.83	0.19		
LVA	B:	6	7.52	1.25	1.84	0.0970
	W:	114	77.54	0.68		
LVHE	B:	6	8.71	1.45	2.23	0.0450*
	W:	114	73.99	0.65		
LVT	B:	6	48.59	8.09	9.90	0.0001*
	W:	114	93.23	0.82		
HAV	B:	6	63234.73	10539.12	1.13	0.3470
	W:	114	1059335.82	9292.42		
KAV	B:	6	647747.97	107957.99	4.35	0.001*
	W:	114	2823986.50	24771.81		
AAV	B:	6	700064.34	116677.39	2.19	0.048*
	W:	114	6055930.22	53122.19		
COM	B:	6	29.79	4.97	90.58	0.0001*
	W:	114	6.25	0.05		
LVB	B:	6	181.77	30.29	40.39	0.0001*
	W:	114	85.54	0.75		

* Indicates significant
B = Between groups variance
W= Within group variance

4.4 EFFECT OF APPROACH ANGLES ON ACCURACY OF THE KICK

Presented in the Table 4.4.1 is the descriptive statistical values of the accuracy of the kick taken from different approach angles (0° to 90° in step of 15°). Figure 4.4.1 depicted the effect of the approach angles on an accuracy of the kick, adjusted for subject differences (see section 3.5). The r-square of 0.80 revealed that fit was good. Results of the two-way ANOVA (Table 4.3.2) revealed that there was a significant effect of AA on the accuracy of the kick ($F=79.63$; $p<.0001$). The highest accuracy was found at an approach of 45°(M= 0.92 m) which was insignificantly different from the approach angle of 60° (M=1.42m) but significantly different from the rest of the AA (0°, 15°, 30°, 75° and 90°). Approach angles of 30° and 60° also exhibited good accuracy both being less than 2m. The results also revealed that the accuracy of the kick reduced as the AA deviated from 45°. The minimum accuracy was found while kick was taken from 0° AA (M=4.11m), which was significantly different from other angles (see AppendixD, Table 2).

Table 4.4.1 Descriptive Statistics of Accuracy of the Kick

Approach Angle	Range (Min - Max)	M (m)	SD (m)
0°	5.18 (2.32-7.50)	4.11	1.19
15°	4.53 (2.00-6.53)	2.96	1.15
30°	2.95 (0.30-3.25)	1.56	0.65
45°	2.18 (0.22-2.40)	0.92	0.43
60°	3.06 (0.39-3.45)	1.42	0.69
75°	3.20 (1.30-4.50)	2.36	0.66
90°	3.15 (2.15-5.30)	3.21	0.67

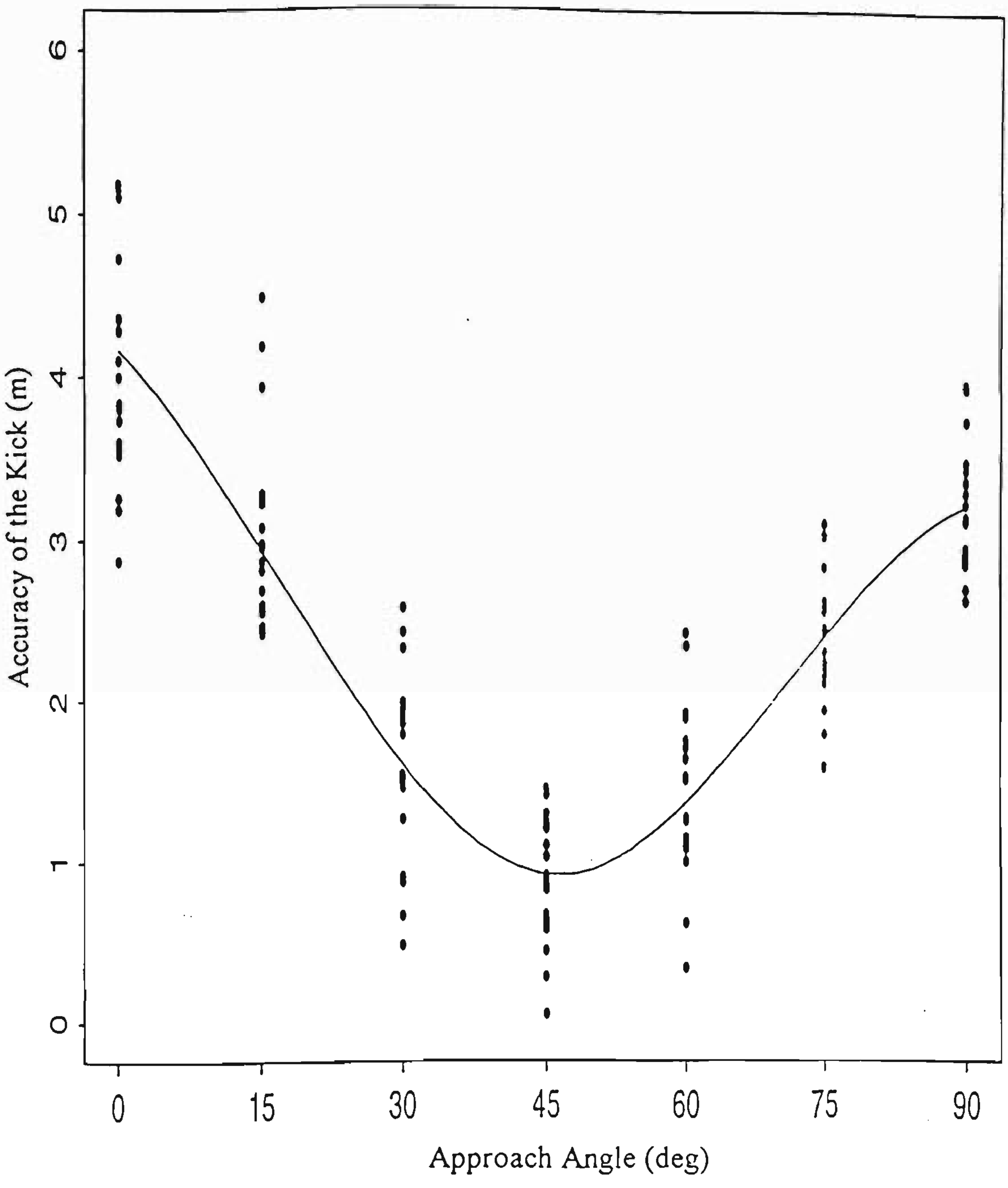


Figure 4.4.1 Effect of Approach Angle on Accuracy of the Kick

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.90$, $r^2 = 0.80$

$$\beta_0 = 0.92$$
$$\beta_1 = -7.45 \times 10^{-3}$$
$$\beta_2 = 3.09 \times 10^{-3}$$
$$\beta_3 = 3.72 \times 10^{-5}$$
$$\beta_{3+} = -7.72 \times 10^{-5}$$

4.5 ANALYSIS OF KINEMATIC VARIABLES

The focus of the study in the kinematic variables obtained by the PEAK 3-D motion analysis system were mainly projected in the linear velocities of the kicking limb (e.g. hip, knee, ankle, heel and toe) and centre of mass (COM) of the whole body and angular velocities of lower limb joints (hip, knee and ankle). These kinematic variables were calculated at the important event of ball contact (BC). Apart from these human body kinematics, the velocity of the ball was also analysed at the event of ball take-off (BTO). From the 3-D linear velocities, velocities along the direction of the target were calculated. For clarity and better understanding of the results found in this area it has been subdivided into the following headings:

(a) Linear velocity of lower limb joints

(b) Linear velocity of distal segment

(c) Linear velocity of the body COM

(d) Linear velocity of ball (LVB)

(e) Angular velocity of lower limb joints

(f) Effect of kicking limb velocities on DCB

4.5.1 Linear velocity of lower limb joints

4.5.1.1 Linear velocity of hip joint

The descriptive statistics of linear velocity of hip along the direction of target at the time of BC is illustrated in Table 4.5.1.1.1. The effect of the approach angles on linear velocity of hip, adjusted for subject differences using the approach angles (see section 3.5) is depicted in the Figure 4.5.1.1.1. From this figure it is evident that the fitted spline was appropriate with a r-square value of 0.76. Result of the Two-Way ANOVA (Table 4.3.2) illustrated that there was a significant effect of AA on LVH ($F=61.62$; $p<0.0001$) The LVH was found maximum while kick was taken from an AA of 0° ($M=1.56$ m/s). It was noted that as the AA increases the velocity of the hip also gradually decreases. The Bonferroni Post Hoc Test shown in the Appendix D, Table 3 illustrated that AA of 30°, 45°, 60°, 75° and 90° were significantly different from AA of 0°. It was also evident that AA of 45°, 60°, 75°and 90° were significantly different from AA of 15°. The AA of 30° and 45° was also significantly different form the approach angles of 60°, 75°and 90°. Approach angle of 60° was significantly different from 90°.

Table 4.5.1.1.1: Descriptive Statistics of Linear Velocity of Hip at BC

Approach Angle	Range (Min - Max)	M (m)	SD (m)
0°	1.75 (0.78-2.53)	1.56	0.46
15°	1.47 (0.60-2.07)	1.39	0.37
30°	1.61 (0.82-2.43)	1.28	0.42
45°	1.27 (0.50-1.77)	1.07	0.40
60°	1.08 (0.05-1.13)	0.61	0.23
75°	0.56 (0.05-0.61)	0.36	0.17
90°	0.99 (0.05-1.04)	0.34	0.25

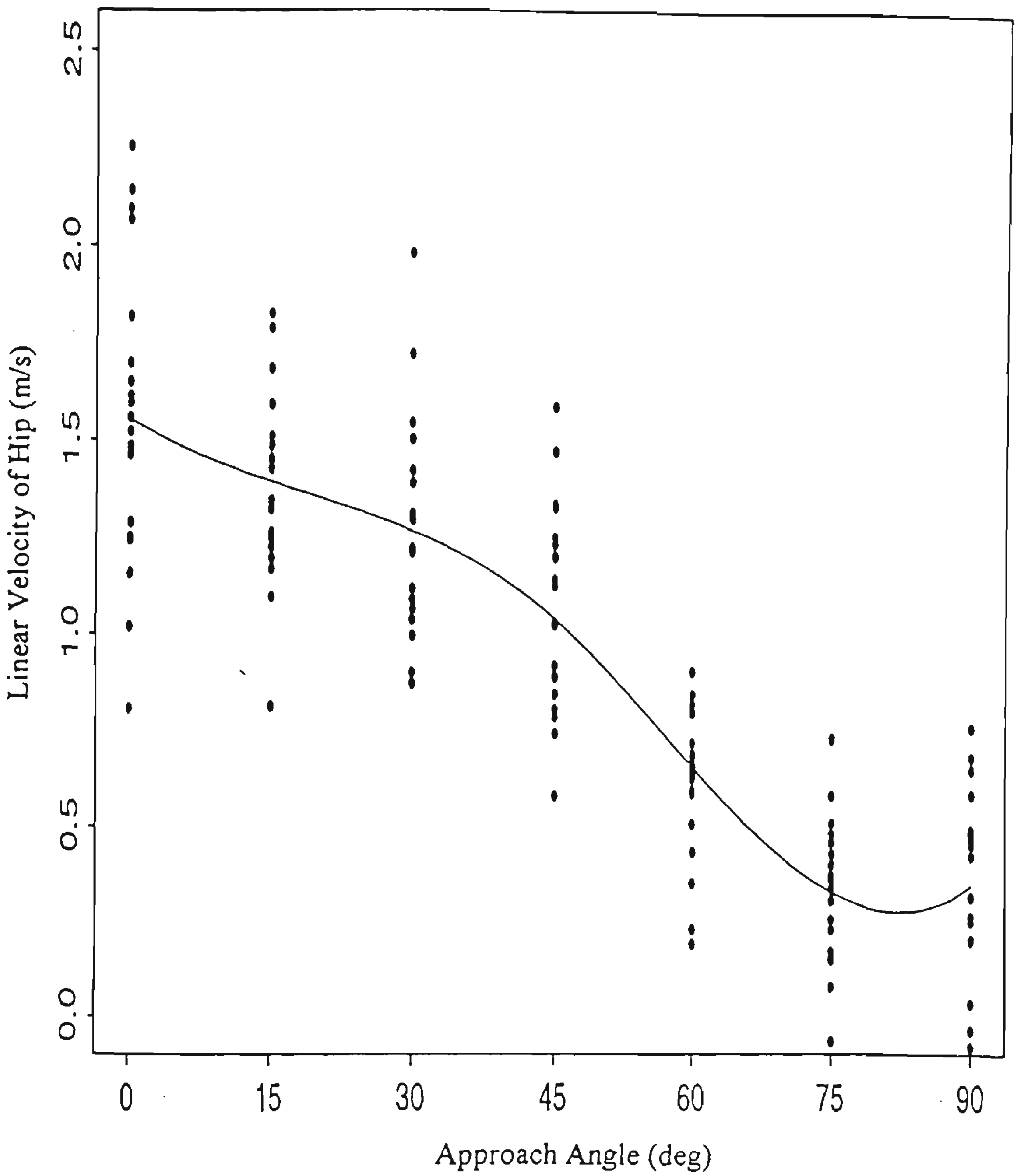


Figure 4.5.1.1.1 Effect of Approach Angle on Linear Velocity of Hip

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.87$, $r^2 = 0.75$

$$\beta_0 = 1.04$$
$$\beta_1 = 2.13 \times 10^{-2}$$
$$\beta_2 = -5.10 \times 10^{-4}$$
$$\beta_3 = -6.46 \times 10^{-6}$$
$$\beta_{3+} = 2.07 \times 10^{-5}$$

4.5.1.2 Linear velocity of knee joint

Table 4.5.1.2.1 illustrated the descriptive statistics of linear velocity of knee at BC. The effect of the approach angle (AA) on linear velocity of knee (LVK), adjusted for subject differences using the AA (see section 3.5) is displayed in Figure 4.5.1.2.1. The part of the result of the Two-Way ANOVA test suggested that there was a significant effect of the approach angles on the LVK (F= 7.92; p=0.0001). The maximum LVK along the direction of target was found while kick was taken from an AA of 30° (M= 3.27 m/s). It was observed that as the AA were increased or decreased from the 30° the LVK decreases gradually. The lowest LVK was noted at an AA of 90° (M=2.46 m/s). The Bonferroni Post Hoc Test (Appendix D, Table 4) revealed that the AA of 90° was significantly different from all other AA. There was also a significance difference between the AA of 0° and 30°.

Table 4.5.1.2.1 Descriptive Statistics of Linear Velocity of Knee

Approach Angle	**Range (Min - Max)**	**M (m/s)**	**SD (m/s)**
0°	3.62 (0.48-4.10)	2.87	0.77
15°	2.31 (2.20-4051)	3.17	0.58
30°	2.83 (1.65-4.48)	3.27	0.69
45°	1.92 (2.11-4.03)	3.20	0.11
60°	2.32 (1.79-4.11)	2.99	0.13
75°	2.07 (1.81-3.88)	2.91	0.12
90°	2.41 (1.11-3.52)	2.46	0.63

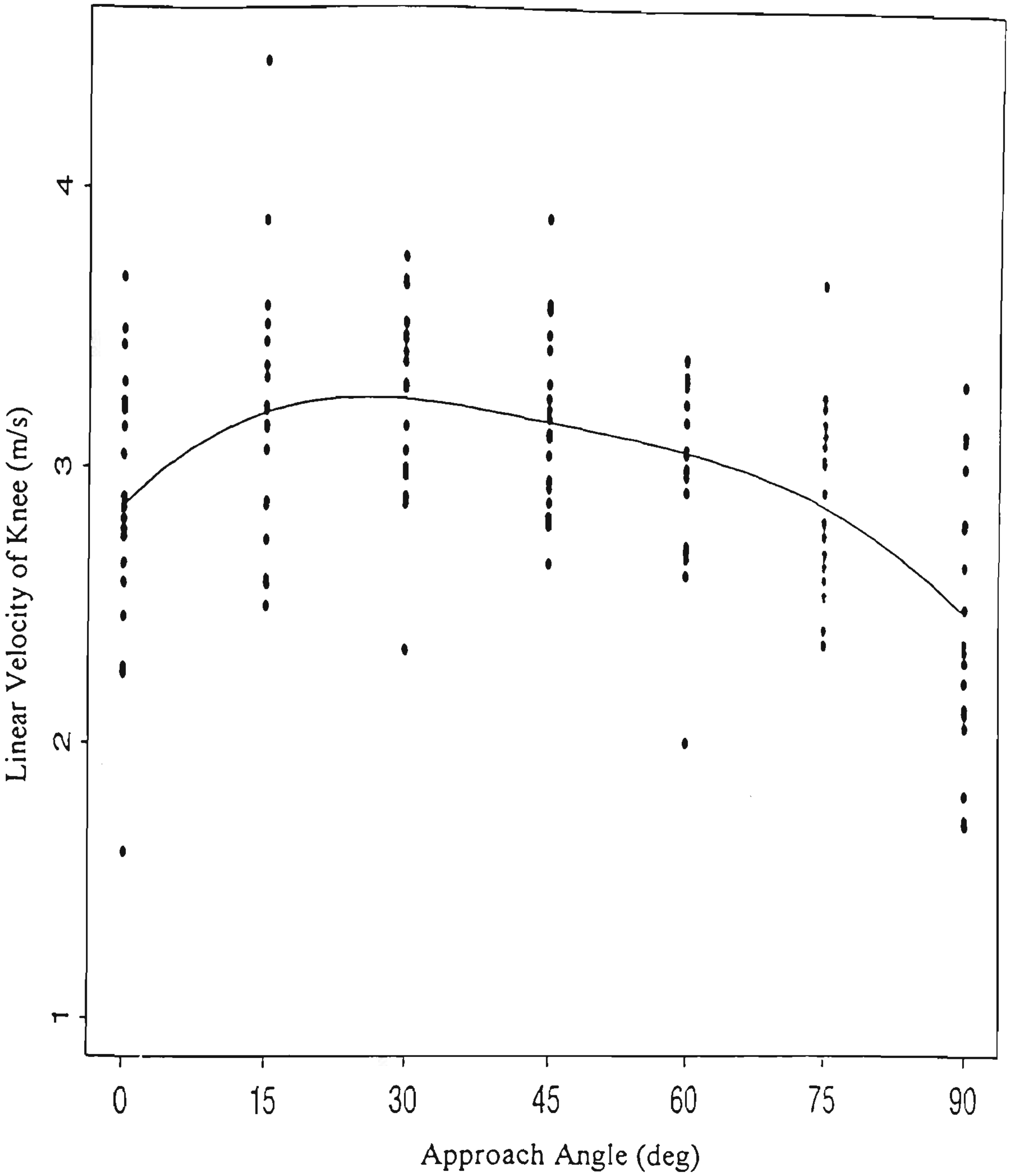


Figure 4.5.1.2.1 Effect of Approach Angle on Linear Velocity of Knee

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.56$, $r^2 = 0.27$

$\beta_0 = 3.16$
$\beta_1 = -6.56 \times 10^{-3}$
$\beta_2 = 4.04 \times 10^{-5}$
$\beta_3 = 7.48 \times 10^{-6}$
$\beta_{3+} = -1.27 \times 10^{-5}$

4.5.1.3 Linear velocity of ankle joint

Table 4.5.1.3.1 describes the descriptive statistical values of linear velocities of ankle (LVA) analysed at the time BC. The over all effect of the AA on LVA, adjusted for subject differences applying the AA (see section 3.5) is projected in the Figure 4.5.1.3.1. The part of the Two-Way ANOVA Test presented in Table 4.3.2 showed non-significant effect of the AA on the LVA ($F=1.84$; $p<0.097$). However the Bonferroni post hoc test (Appendix D, Table 5) revealed the significant differences between the approach angle of 90° (M=9.94 m/s) and 30° (M=10.73 m/s). The maximum LVA (M= 10.73 m/s) generated was from the AA of 30° and lowest was from the AA of 90° (M=9.94 m/s).

Table 4.5.1.3.1 Descriptive Statistics of Linear Velocity of Ankle at BC

Approach Angle	Range (Min - Max)	M (m/s)	SD (m/s)
0°	3.83 (7.79-11.62)	10.19	0.94
15°	8.50 (3.26-11.76)	10.29	1.76
30°	4.10 (8.37-12.47)	10.73	1.05
45°	3.60 (8.48-12.08)	10.47	0.99
60°	2.75 (8.77-11.52)	10.39	0.82
75°	3.15 (8.66-11.81)	10.48	0.77
90°	3.53 (8.12-11.65)	9.94	0.99

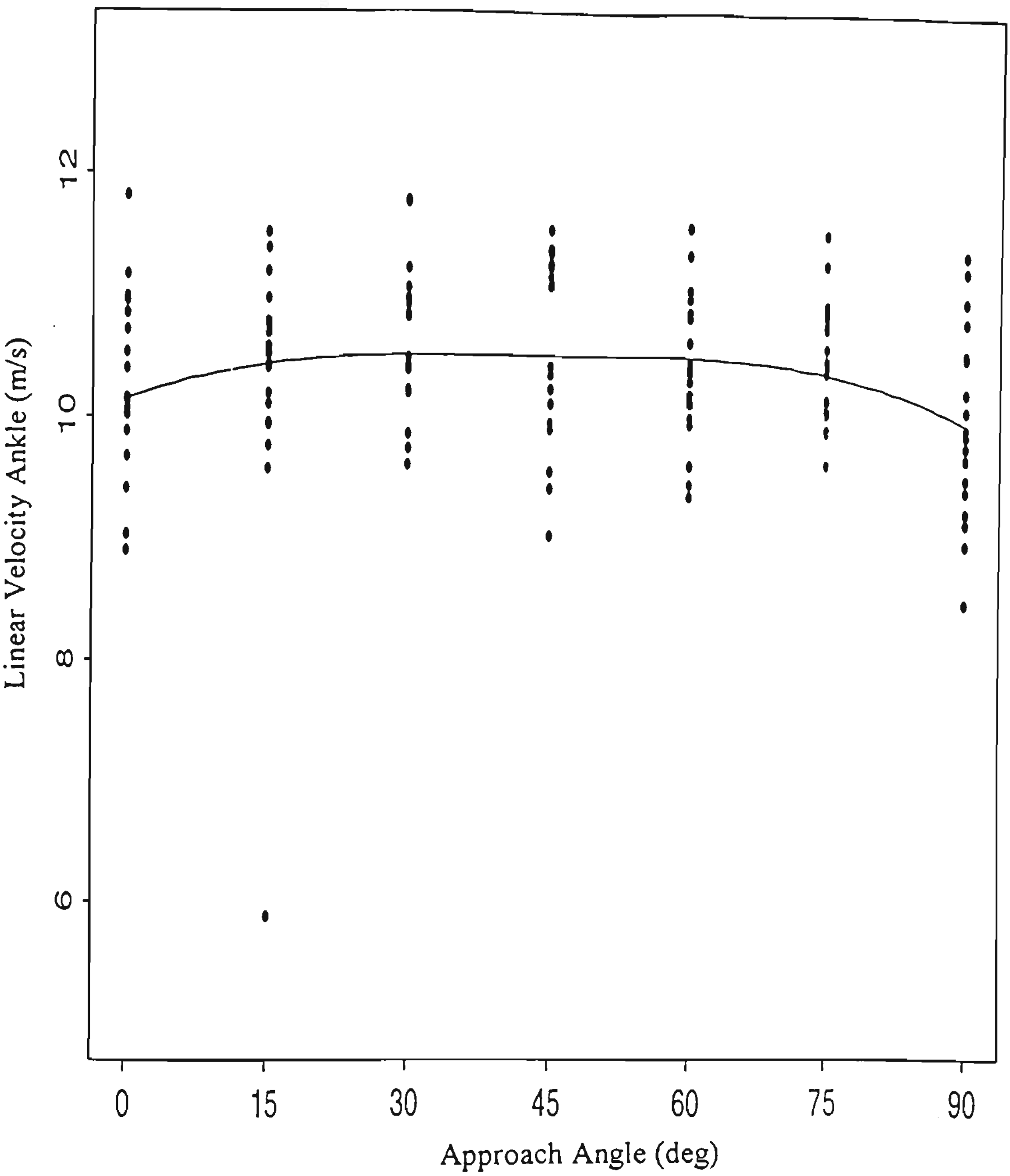


Figure 4.5.1.3.1 Effect of Approach Angle on Linear Velocity of Ankle

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.26$, $r^2 = 0.04$

$\beta_0 = 10.53$
$\beta_1 = -3.26 \times 10^{-4}$
$\beta_2 = 8.01 \times 10^{-5}$
$\beta_3 = 5.96 \times 10^{-6}$
$\beta_{3+} = -1.37 \times 10^{-5}$

4.5.2 Linear velocity of distal segment

4.5.2.1 Linear velocity of heel

Table 4.5.2.1.1 displays the descriptive statistics of linear velocity of the heel (LVHE) at BC. Figure 4.5.2.1.1 explained the effect of the approach angles on LVHE adjusted for subject differences using the AA (see section 3.5) at BC. Two Way ANOVA result presented in Table 4.3.2 showed marginal significance effect of the AA on LVHE ($F=2.23$; $p<0.045$). However Bonferroni post hoc test failed to show any significant differences between the means. The maximum LVHE along the direction of target was noted while kick was executed from an AA of 15° (M=11.91 m/s) and the minimum was at 90° (M=11.19 m/s).

Table 4.5.2.1.1 Descriptive Statistics of Linear Velocity of Heel at BC

Approach Angle	Range (Min - Max)	M (m/s)	SD (m/s)
0°	3.40 (9.94-13.34)	11.80	0.95
15°	3.51 (9.25-13.29)	11.91	0.19
30°	4.04 (9.25-13.29)	11.87	1.10
45°	2.88 (10.04-12.92)	11.66	0.81
60°	3.48 (9.66-13.14)	11.43	1.01
75°	4.29 (8.57-12.86)	11.44	1.10
90°	3.89 (9.17-13.06)	11.19	1.17

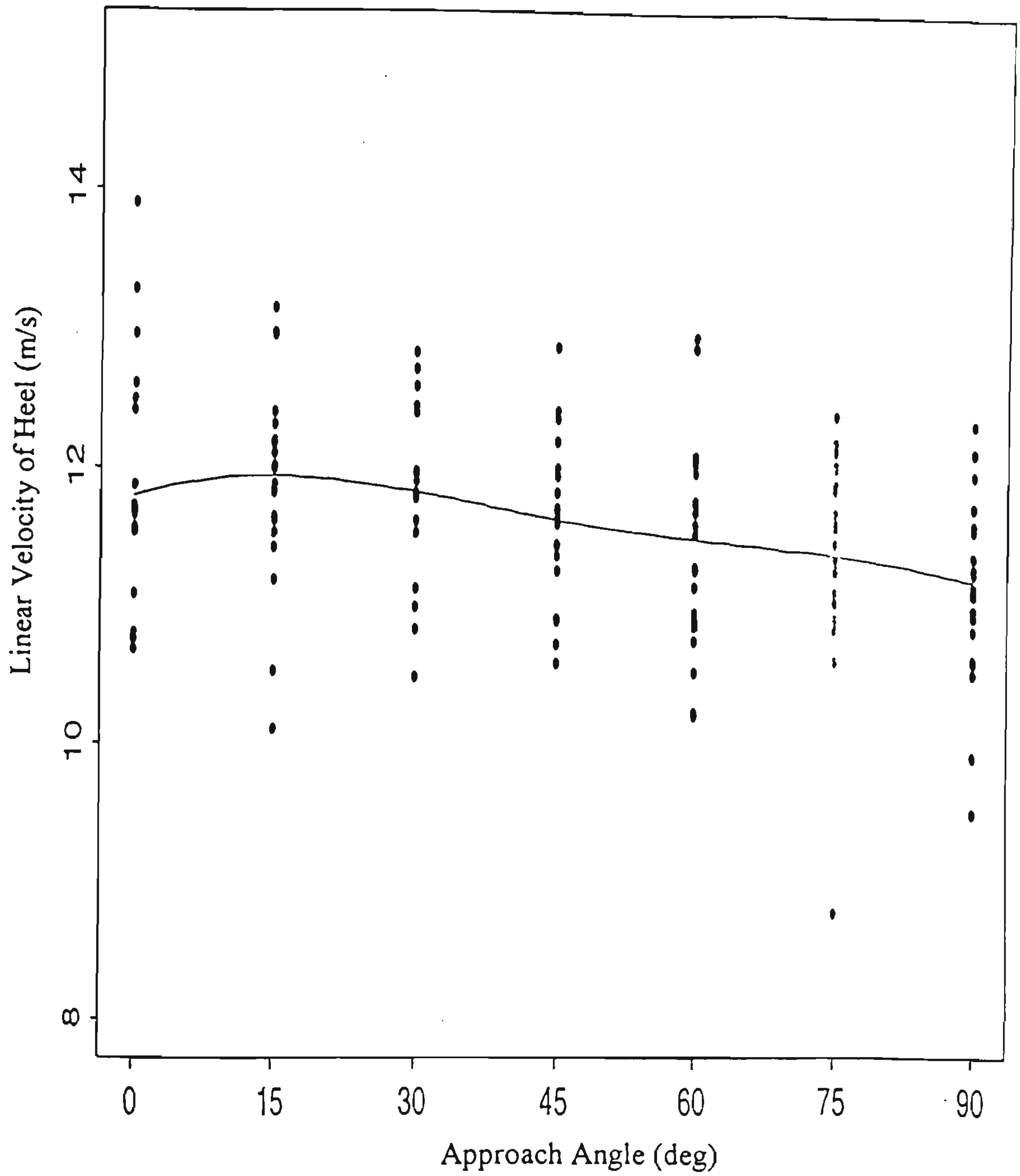


Figure 4.5.2.1.1 Effect of Approach Angle on Linear Velocity of Heel

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.32$, $r^2 = 0.08$

$\beta_0 = 11.64$
$\beta_1 = -1.14 \times 10^{-2}$
$\beta_2 = 2.31 \times 10^{-4}$
$\beta_3 = 9.09 \times 10^{-6}$
$\beta_{3+} = -1.33 \times 10^{-5}$

4.5.2.2 Linear velocity of toe

The descriptive statistics of linear velocity of toe at BC is presented in Table 4.5.2.2.1. Result of the Two-Way ANOVA (Table 4.3.2) revealed the existence of a significant effect of the AA on LVT (F=9.90; p<0.0001). Figure 4.5.2.2.1 represents this effect of the AA on LVT, adjusted for the subject differences using the AA (see section 3.5). The post hoc test (Appendix D, Table 6) showed that the AA of 0° (M=11.90 m/s) was significantly different from the AA of 15°, 30°, 45°, 60° and 75°. The LVT at 90° (M=12.45 m/s) AA was also found significantly different from that at AA of 30° and 45°. The maximum LVT was yielded at an AA 45°.

Table 4.5.2.2.1 Descriptive Statistics of Linear Velocity of Toe at BC

Approach Angle	Range (Min - Max)	M (m/s)	SD (m/s)
0°	3.89 (9.89-13.78)	11.90	1.05
15°	5.54 (9.93-15.47)	13.02	1.23
30°	4.19 (11.45-15.64)	13.74	1.16
45°	3.85 (10.81-14.66)	13.62	1.06
60°	4.07 (10.62-14.69)	13.01	1.01
75°	3.76 (11.03-14.79)	13.03	0.89
90°	3.52 (10.73-14.25)	12.45	1.01

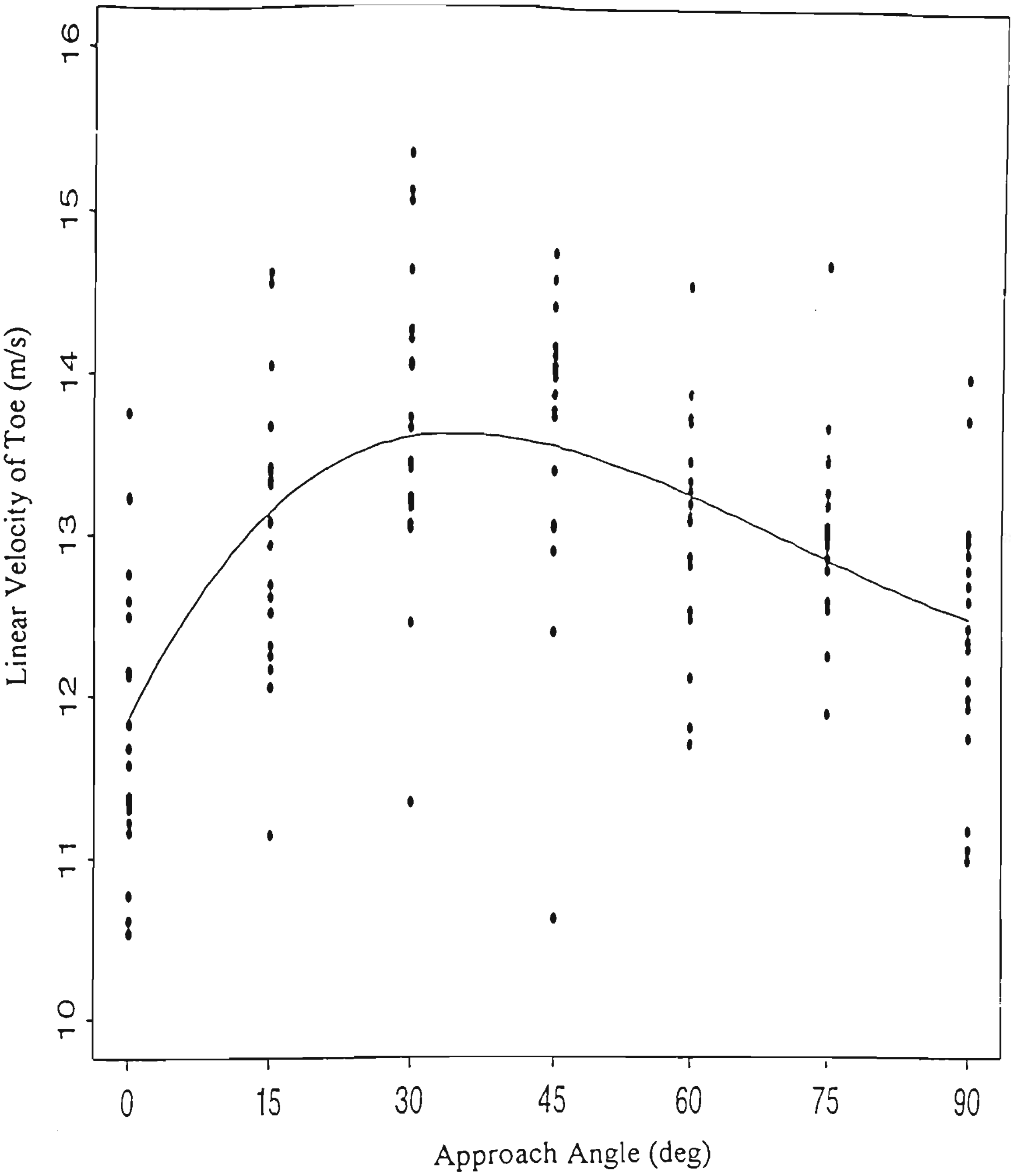


Figure 4.5.2.2.1 Effect of Approach Angle on Linear Velocity of Toe

Cubic Spline Coefficients (see equation 1, section 3.5): R = 0.57, $r^2 = 0.30$

$$\beta_0 = 13.55$$
$$\beta_1 = -1.41 \times 10^{-2}$$
$$\beta_2 = -4.92 \times 10^{-4}$$
$$\beta_3 = 1.45 \times 10^{-5}$$
$$\beta_{3+} = -8.20 \times 10^{-6}$$

4.5.3 Linear velocity of the body COM

The descriptive statistics of the COM linear velocity at BC is presented in Table 4.5.3.1. Figure 4.5.3.1 shows the effect of the AA on linear velocity of COM, adjusted for subject differences using the AA (see section 3.5). It was noted from the ANOVA table (Table 4.3.2) that AA has significant effect on COM velocity ($F=90.58$; $p<0.0001$). Like the hip joint the COM linear velocity was maximum at AA 0°. It was seen to be relatively constant up to 45° after which it rapidly decreased with minimum at 90°. The post hoc test (Appendix D, Table 7) revealed that COM velocity at 60° AA was significantly different from other AA. Further, the AA of 75° (M=1.16 m/s) was significantly different from the AA of 0°, 15°, 30°, 45° and 90°. The AA of 90° (M=0.65 m/s) was also found significantly different from the AA of 0°, 15°, 30° and 45°.

Table 4.5.3.1 Descriptive Statistics of Linear Velocity of Centre of Mass at BC

Approach Angle	Range (Min - Max)	M (m/s)	SD (m/s)
0°	2.11 (0.77-2.88)	1.98	0.41
15°	1.57 (1.17-2.74)	1.93	0.36
30°	1.66 (1.28-2.94)	1.92	0.42
45°	1.45 (1.04-2.49)	1.80	0.37
60°	1.03 (0.90-1.93)	1.43	0.28
75°	1.11 (0.54-1.65)	1.16	0.29
90°	0.82 (0.16-0.98)	0.65	0.22

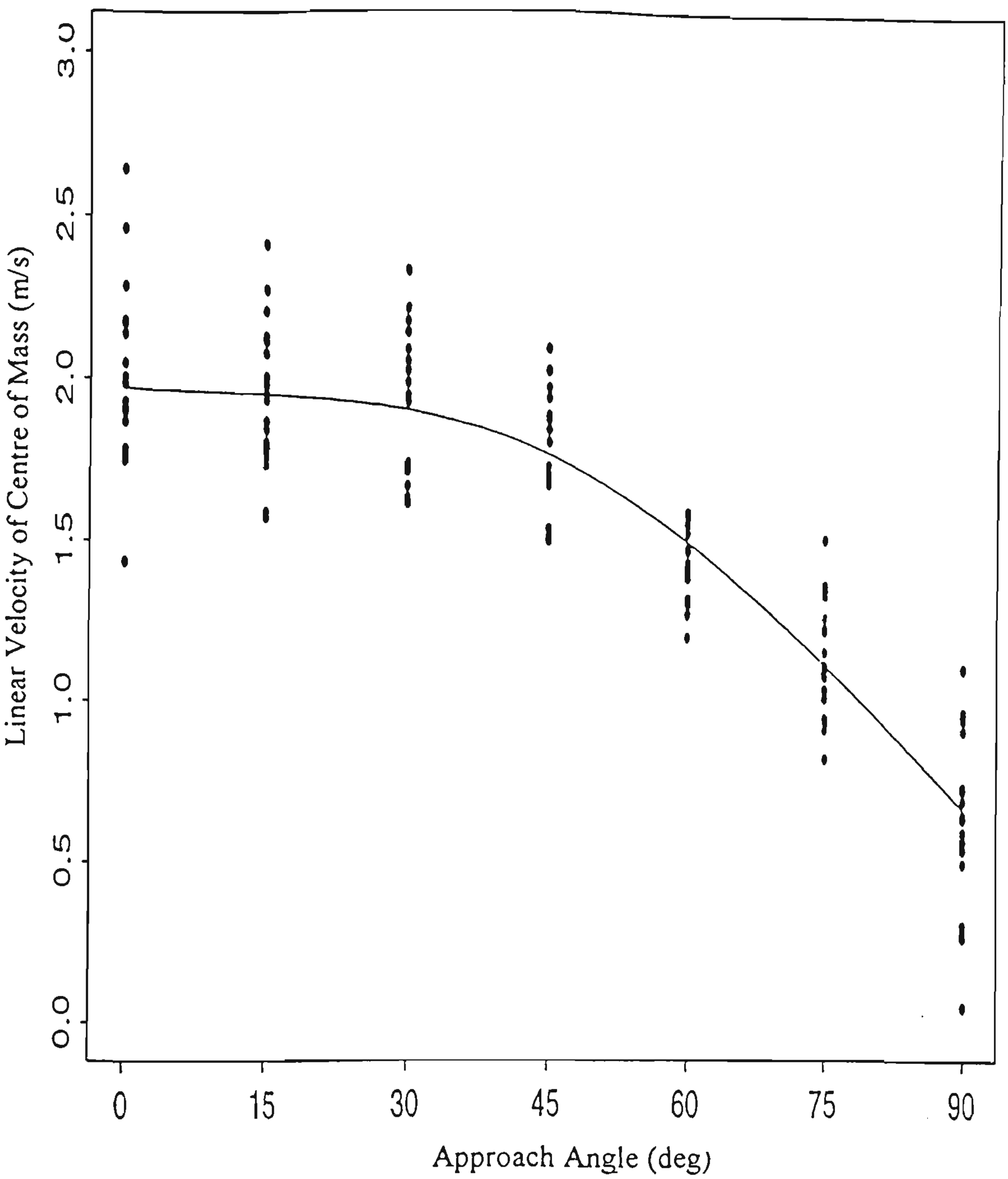


Figure 4.5.3.1 Effect of Approach Angle on Linear Velocity of Centre of Mass

Cubic Spline Coefficients (see equation 1, section 3.5): R = 0.90, $r^2 = 0.82$

β_0 = 1.77
β_1 = -1.34×10^{-2}
β_2 = -3.43×10^{-4}
β_3 = -3.23×10^{-6}
β_{3+} = 5.44×10^{-6}

4.5.4 Linear velocity of ball

Presented in Table 4.5.4.1 is the summary of the descriptive statistics of the linear velocity of ball at BTO (Ball take-off). Figure 4.5.4.1 shows the effect of the AA on linear velocity of the ball (LVB), adjusted for subject differences using the approach angles (see section 3.5). Part of the ANOVA table (Table 4.3.2) suggested that there was a significant effect of the AA on LVB at BTO ($F=40.39$; $p<0.0001$). The maximum LVB was observed while kicks were executed from the AA of 30° - 60° and highest being noted at an AA of 45°(M=18.61m/s). The Bonferroni Post-Hoc Test (Appendix D, Table 8) showed that the velocity generated at an AA of 45° was significantly different from the rest of AA. It is interesting to note that the ball velocity at 0° AA, which generated minimum ball velocity, was also significantly different from the rest of AA. The LVT at 15° AA was significantly different from 30° and 60° AA. Further, investigation revealed that AA of 90° was also significantly different from 30°, 60° and 75°. LVT at 30° and 75° were also significantly different from each other.

Table 4. 5.4.1 Descriptive Statistics of Linear Velocity of Ball at BTO

Approach Angle	Range (Min- Max)	M (m/s)	SD (m/s)
0°	4.34 (12.29-16.64)	14.92	0.98
15°	4.19 (14.39-18.58)	16.47	1.31
30°	5.50 (14.70-20.20)	17.68	1.57
45°	5.00 (15.72-20.72)	18.61	1.48
60°	4.26 (14.86-19.12)	17.36	1.18
75°	4.28 (14.70-18.98)	16.65	1.11
90°	4.06 (13.68-17.74)	15.77	0.99

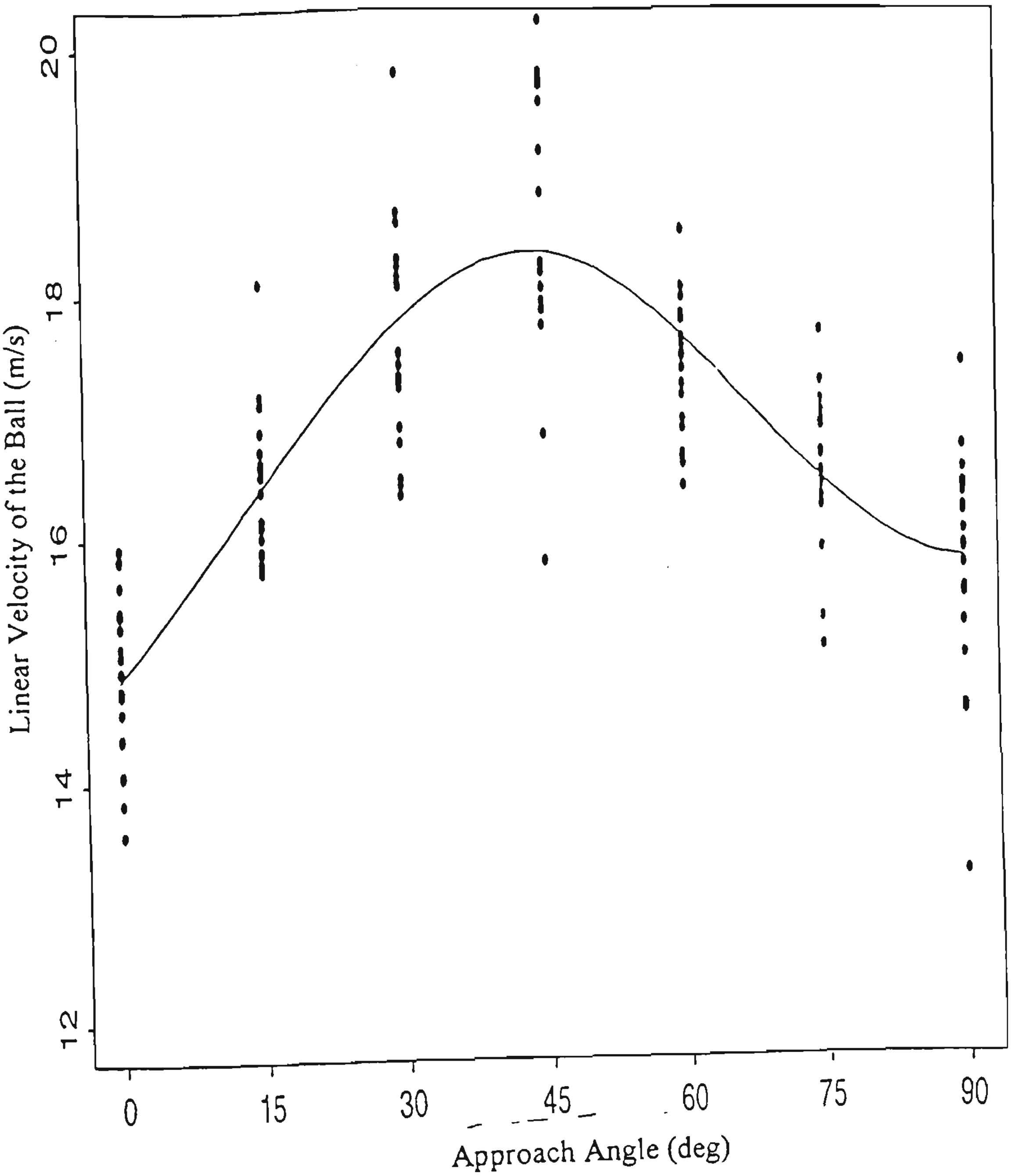


Figure 4.5.4.1 Effect of Approach Angle on Linear Velocity of the Ball

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.82$, $r^2 = 0.65$

$\beta_0 = 18.35$
$\beta_1 = -6.71 \times 10^{-3}$
$\beta_2 = -3.38 \times 10^{-3}$
$\beta_3 = -3.42 \times 10^{-5}$
$\beta_{3+} = 8.49 \times 10^{-5}$

4.5.5 *Angular Velocity of Lower Limb Joints*

4.5.5.1 Angular velocity of hip (HAV)

Table 4.5.5.1.1 displays the summary of the descriptive statistics of angular velocity of the hip joint. Results of ANOVA test (Table 4.3.2) showed that there was no significant effect of AA on HAV (F=1.32; p= 0.347). Figure 4.5.5.1.1 displays this relationship in graphical form. The maximum HAV was found while kick was taken from an AA of 45°.

Table 4.5.5.1.1 Descriptive Statistics of Angular Velocity of Hip at BC

Approach Angle	Range (Min – Max)	M (deg/s)	SD (deg/s)
0°	393.15 (12.72-405.87)	153.96	111.69
15°	264.71 (13.54-278.25)	142.02	71.28
30°	313.94 (0.18-314.12)	156.98	82.60
45°	348.65 (7.25-355.90)	201.85	96.60
60°	409.56 (2.16-411.72)	142.52	129.78
75°	450.79 (14.26-465.05)	188.61	128.87
90°	430.65 (2.47-433.12)	170.24	127.57

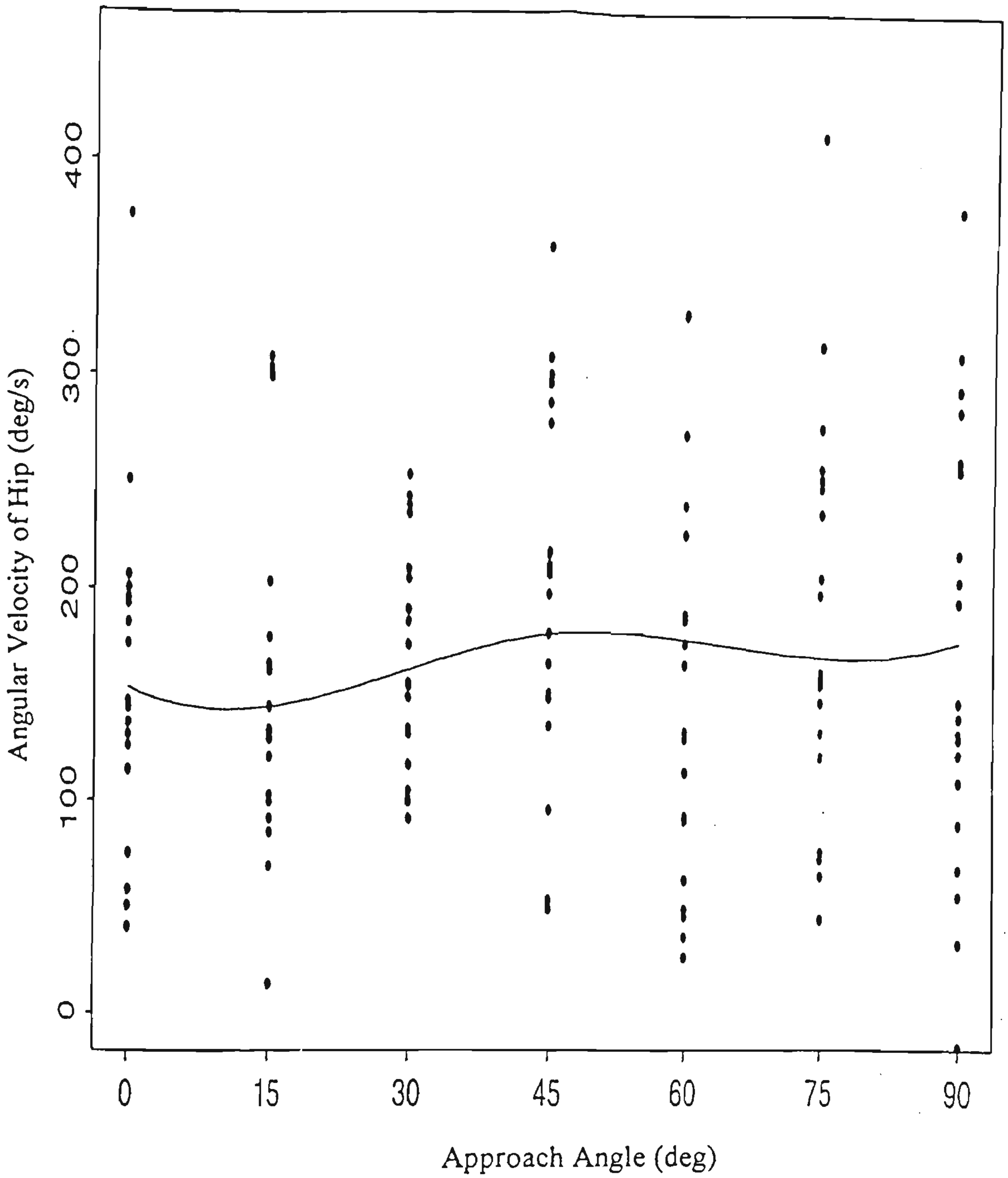


Figure 4.5.5.1.1 Effect of Approach Angle on Angular Velocity of Hip

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.13$, $r^2 = -0.01$

$\beta_0 = 181.17$
$\beta_1 = 0.51$
$\beta_2 = -6.17 \times 10^{-2}$
$\beta_3 = -1.35 \times 10^{-3}$
$\beta_{3+} = 2.43 \times 10^{-3}$

4.5.5.2 Angular velocity of knee (KAV)

Table 4.5.5.2.1 presents the descriptive statistics of angular velocity of knee. The ANOVA results (Table 4.3.2) suggested that there was a significant effect of AA on the KAV ($F=4.35$; $p<0.001$). Figure 4.5.5.2.1 displays this effect of the AA on KAV, adjusted for subject differences using the AA (see section 3.5). Post hoc test (Appendix D, Table 9) revealed that AA of 0° (M=819.18 deg/s), which was maximum was significantly different from the AA of 75° (M= 650.35 deg/s) and 90° (M=624.97 deg/s). The AA of 90° was also significantly different from the AA of 15° (M=769.88 deg/s), 30° (M=783.84 deg/s) and 60° (M=777.66 deg/s). It was noted that as the AA increases the KAV decreases.

Table 4.5.5.2.1 Descriptive Statistics of Angular Velocity of Knee at BC

Approach Angle	Range (Min – Max)	M (deg/s)	SD (deg/s)
0°	493.90 (547.31-1068.21)	819.18	151.29
15°	1177.42 (0.43-1178.15)	769.88	225.64
30°	470.82 (531.90-1002.72)	783.84	119.01
45°	675.43 (361.88-1037.31)	765.15	169.42
60°	608.91 (484.59-1093.50)	777.66	142.09
75°	606.56 (281.05-887.61)	650.35	154.34
90°	577.57 (306.97-884.54)	624.97	176.66

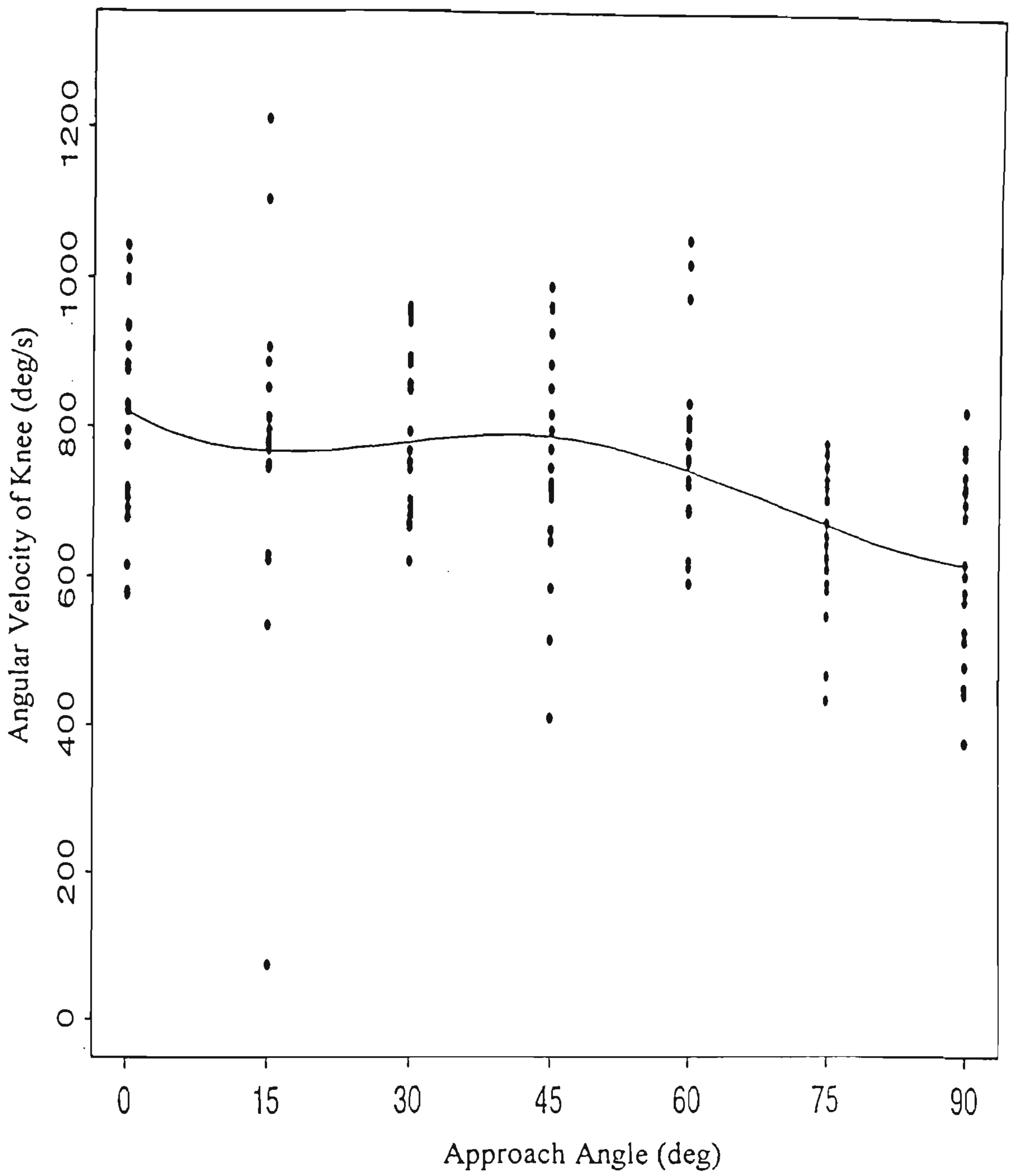


Figure 4.5.5.2.1 Effect of Approach Angle on Angular Velocity of Knee

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.42$, $r^2 = 0.15$

β_0 = 788.47
β_1 = - 1.08
β_2 = - 0.16
β_3 = -3.41×10^{-3}
β_{3+} = 5.68×10^{-3}

4.5.5.3 Angular velocity of ankle (AAV)

Means and standard deviations of AAV are shown in Table 4.5.5.3.1. Unlike the KAV, AAV increased as approach angles were increased. ANOVA test (Table 4.3.2) reveals the marginal significant effect of AA on AAV ($F=2.19$; $p<0.048$). However post hoc test failed to display significant differences between the means of the AAV. Figure 4.5.5.3.1 depicts the spline curve showing the effect of AA on AAV.

Table 4.5.5.3.1 Descriptive Statistics of Angular Velocity of Ankle at BC

Approach Angle	Range (Min - Max)	M (deg/s)	SD (deg/s)
0°	937.01 (31.04-968.05)	350.21	239.62
15°	1176.28 (16.23-1192.51)	370.52	309.77
30°	1008.51 (40.66-1049.17)	353.73	255.58
45°	823.47 (19.47-842.94)	388.99	271.94
60°	986.64 (5.97-992.61)	401.23	274.61
75°	921.16 (27.30-948.46)	516.49	233.63
90°	968.96 (5.27-974.23)	532.98	226.92

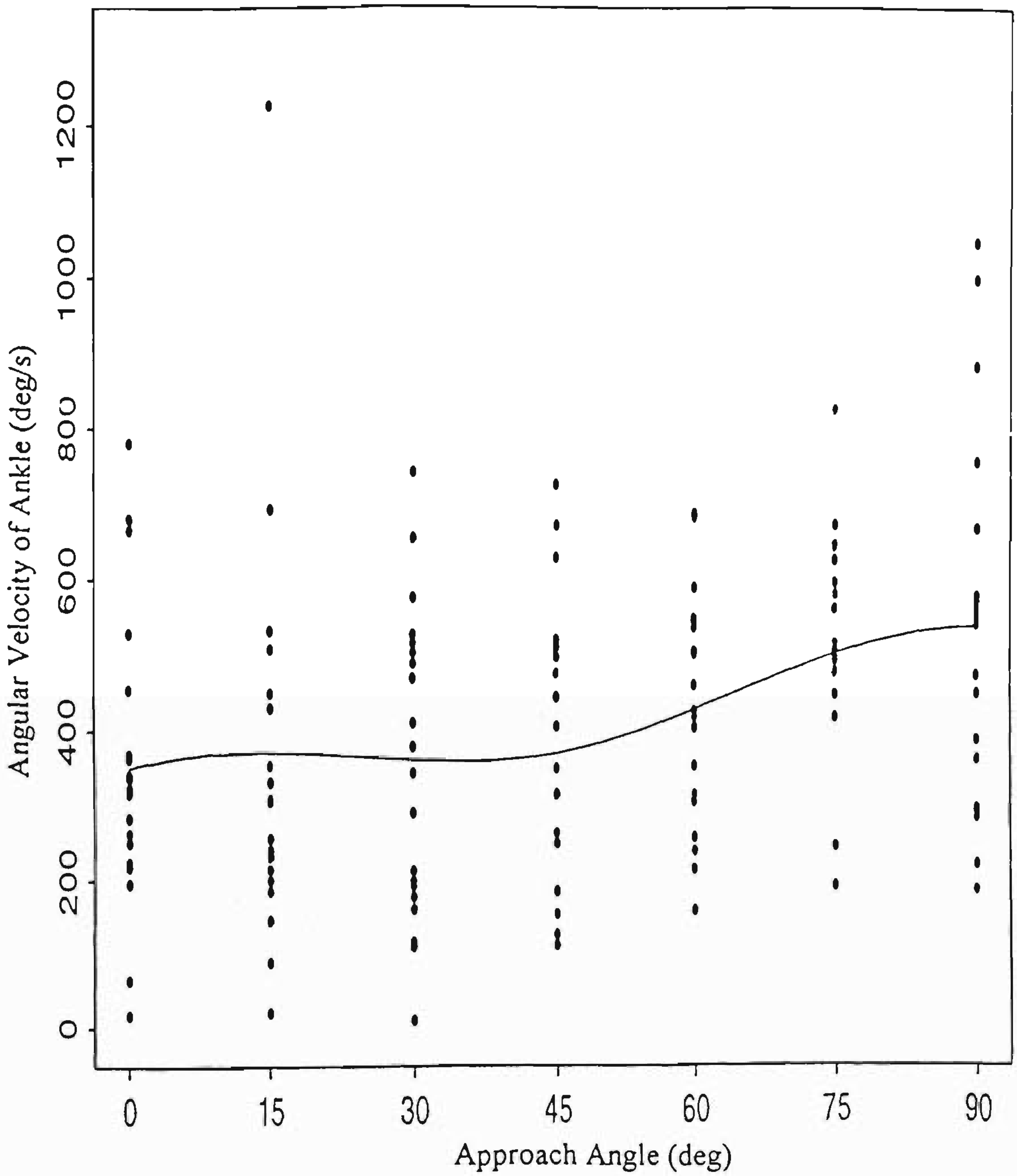


Figure 4.5.5.3.1 Effect of Approach Angle on Angular Velocity of Ankle

Cubic Spline Coefficients (see equation 1, section 3.5): $R = 0.89$, $r^2 = 0.78$

β_0 = - 463.64
β_1 = 2.25
β_2 = 0.15
β_3 = 2.38×10^{-3}
β_{3+} = $- 4.93 \times 10^{-3}$

4.5.6 Effect of Kicking Limb Velocities on DCB

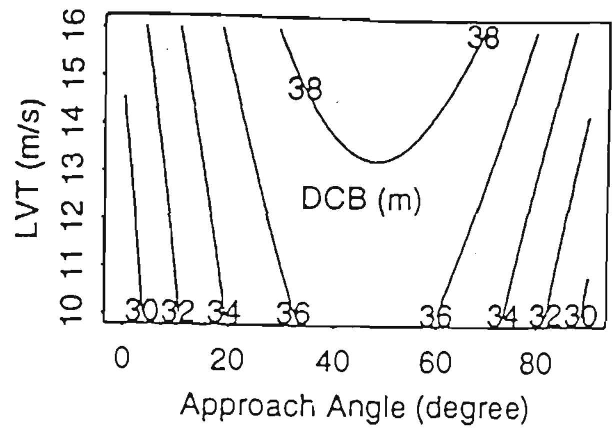
4.5.6.1 Effect of kicking limb and body COM linear velocities on DCB

In order to find out the effect of linear velocities of major lower limb joints (hip, knee and ankle), foot segment (heel and toe) and COM of the whole body on DCB, a stepwise regression analysis was carried out. The results revealed that except for the linear velocity of toe ($t=2.245$, $p<0.027$), the rest of the variables were non-significant. A second order quadratic model involving AA and LVT as independent variables and DCB as dependent variable was fitted to the data according to the following equation:

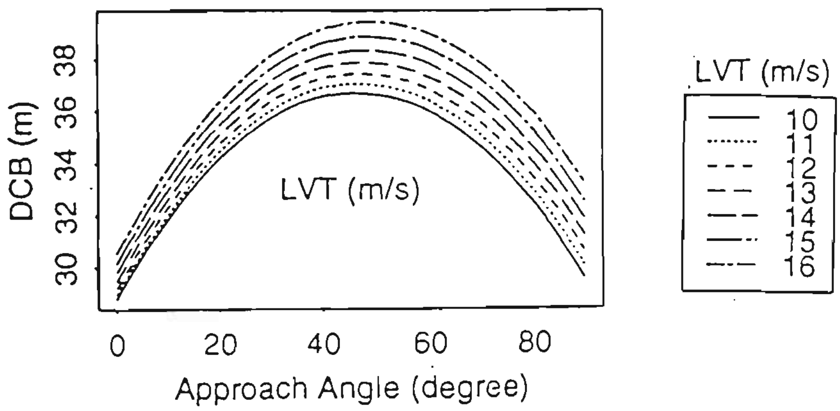
$$DCB = \beta_0 + \beta_1 LVT + \beta_2 AA + \beta_{11} LVT^2 + \beta_{22} AA^2 + \beta_{12} (AA)(LVT) + \varepsilon \quad ......(1)$$

Where β_i = Coefficients and ε = Error

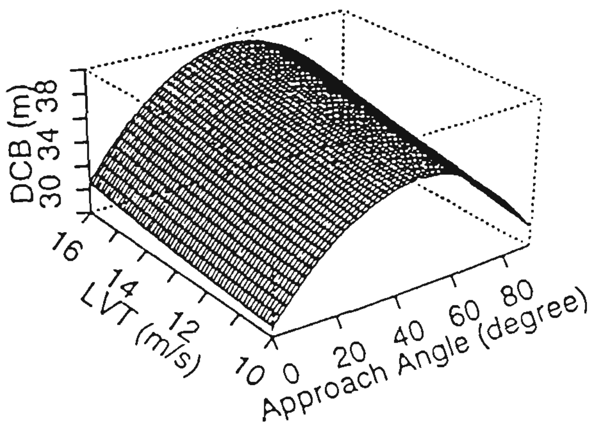
Figure 4.5.6.1.1(a) shows a contour plot of the fitted equation showing the relationship between LVT and AA for different DCB's. Figure 4.5.6.1.1(b) shows an alternative view of this equation displaying the relationship between DCB and AA for LVT in the range 10 to 16 m/s. Figure 4.5.6.1.1(c) shows a 3-D representation of the fitted model. The plots shows that maximum distance is achievable with an approach angle of 45° and also larger LVTs increase the maximum DCB.



(a) Contour plot showing the relationship among the AA, LVT and DCB



(b) Plot showing the relationship between AA and DCB for value of LVT = 10, 11,...16 m/s



(c) 3-Dimensional plot showing the relationship among the AA, LVT and DCB

Figure 4.5.6.1.1 Plots Showing the Linear Velocity of Toe (LVT) and Approach Angle (AA) Variations on Distance Covered by the Ball (DCB)

4.5.6.2 Effect of kicking limb angular velocities on DCB

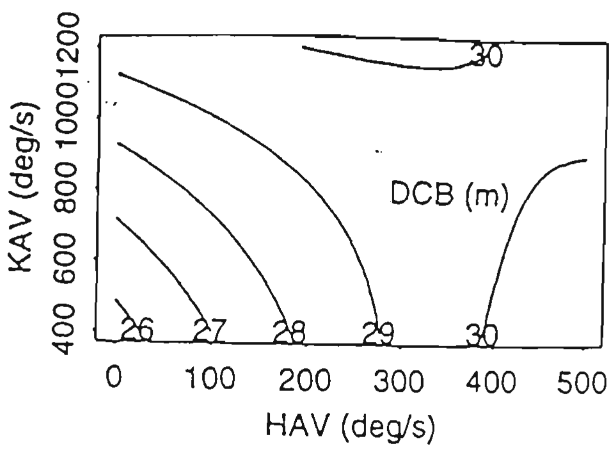
Stepwise regression results suggest that the hip ($t = 3.21$; $p < 0.002$) and knee ($t = 2.82$; $p < 0.006$) angular velocities contributed significantly on DCB. The ankle angular velocity (AAV) failed to contribute significantly. A second order quadratic model was fitted to the data using AA, HAV and KAV as explanatory variables and DCB as the response variable

$$DCB = \beta_0 + \beta_1 \text{ Angle} + \beta_2 \text{ HAV} + \beta_3 \text{ KAV} + \beta_{11} \text{ Angle}^2 + \beta_{22} \text{ HAV}^2 + \beta_{33} \text{ KAV}^2 + \beta_{12} \text{ Angle (HAV)} + \beta_{13} \text{ Angle (KAV)} + \beta_{23} \text{ (HAV) (KAV)} + \varepsilon \ldots\ldots\ldots\ldots\ldots (2)$$

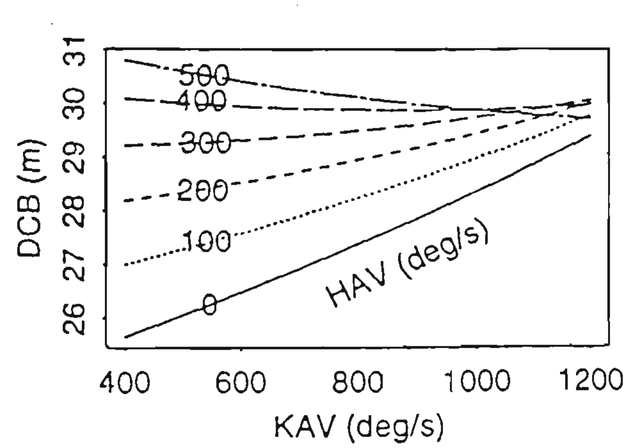
Where β_i= Coefficients, Angle = AA (0° to 90° in step of 15°) and ε = Error

Figure 4.5.6.2.1(a) shows a contour plot of the fitted equation giving predicted DCB's for values of KAV and HAV (with angle set to 0°). Based on the above equation Figure 4.5.6.2.1(b) gives predicted DCB vs. KAV with HAV set to 0, 100,...., 500 deg/s. Figure 4.5.6.2.1(c) displays a 3-D plot of the relationship between DCB, HAV and KAV.

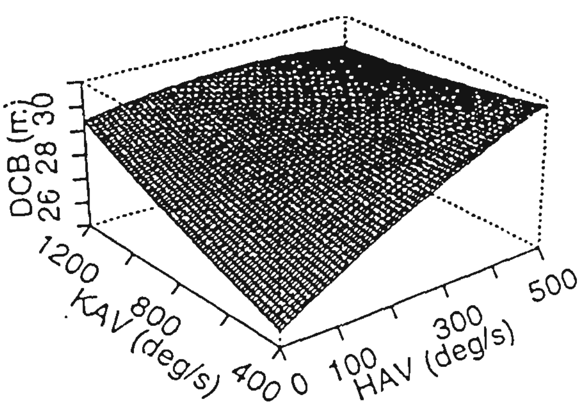
Similarly plots for AA 15° to 90° in steps of 15° are given in Figures 4.5.6.2.2 to 4.5.6.2.7 respectively. The major conclusion was that the predicted DCB increases roughly linearly with KAV when HAV was small, while DCB does not depend much on KAV when HAV was large. However, the largest effect on DCB was the AA with maximum DCB occurring at 45°.



(a) Contour plot showing the relationship between HAV and KAV for various DCB's

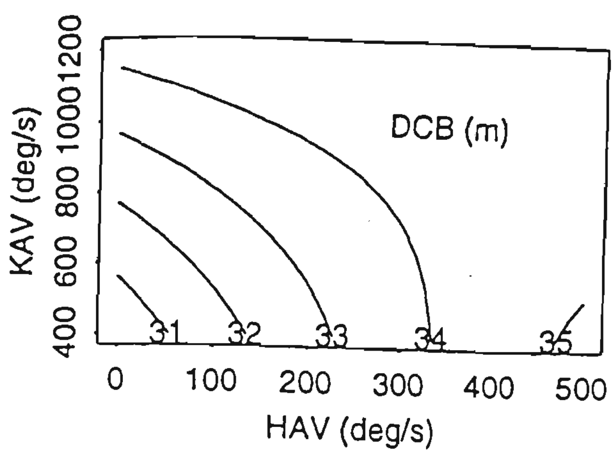


(b) Plot showing the relationship between DCB and KAV for different HAV

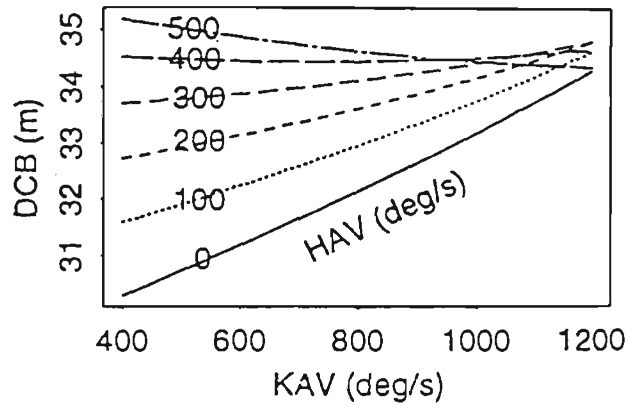


(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

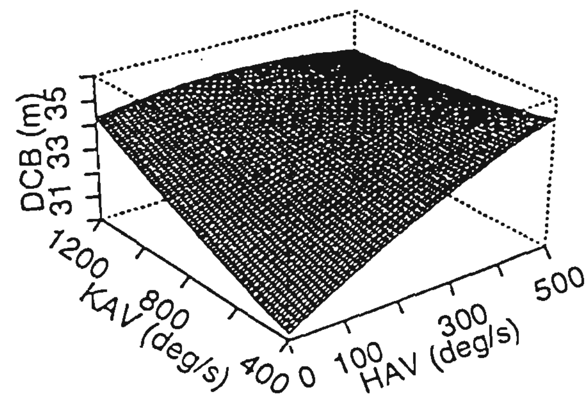
Figure 4.5.6.2.1 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 0°



(a) Contour plot showing the relationship between HAV and KAV for various DCB's

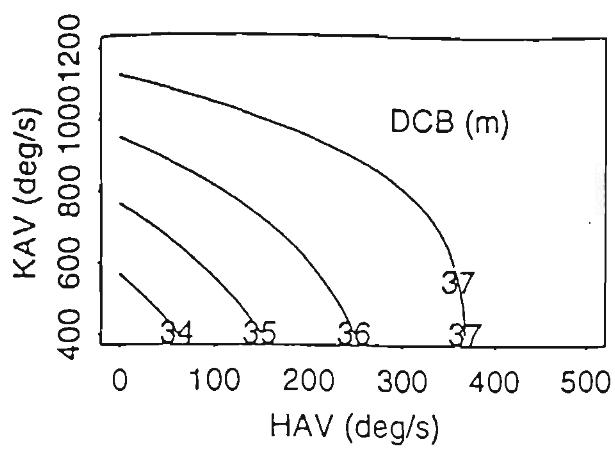


(b) Plot showing the relationship between DCB and KAV for different HAV

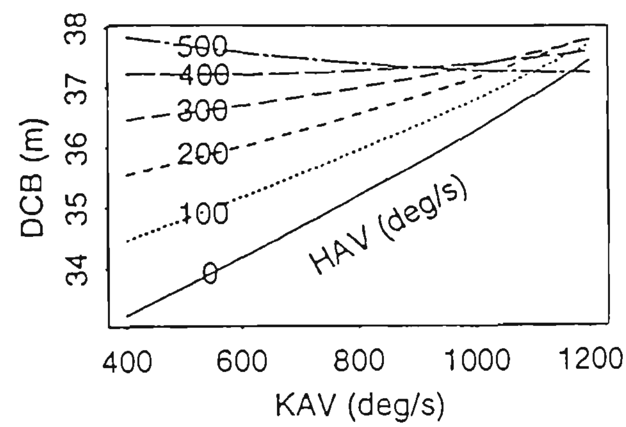


(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

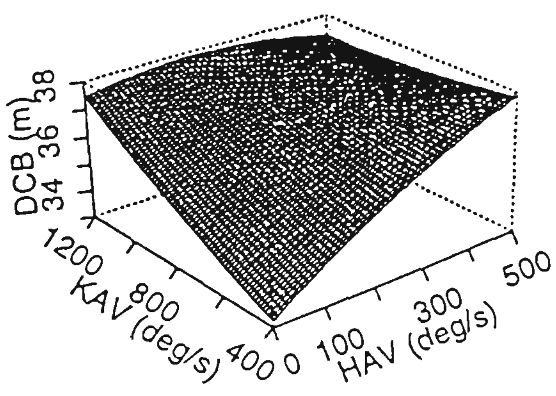
Figure 4.5.6.2.2 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 15°



(a) Contour plot showing the relationship between HAV and KAV for various DCB's

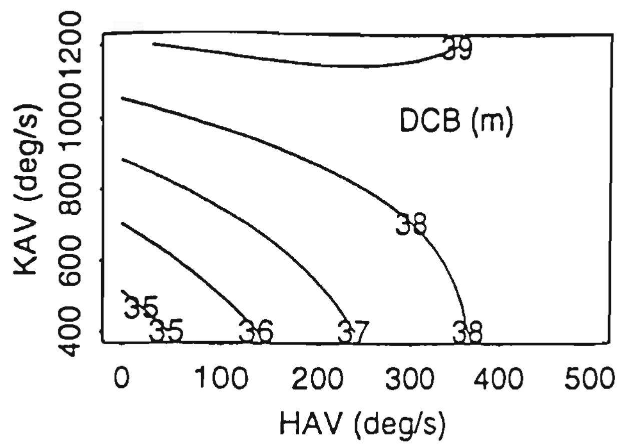


(b) Plot showing the relationship between DCB and KAV for different HAV

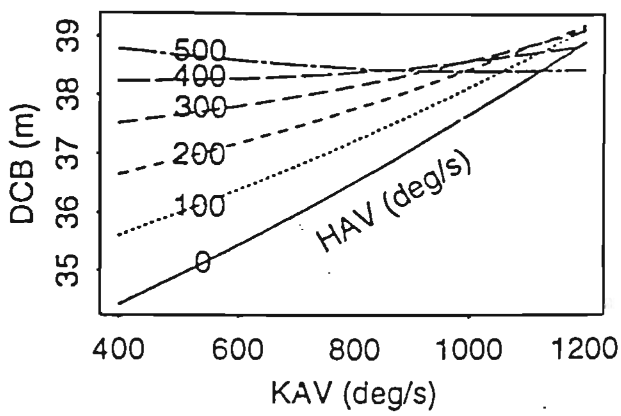


(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

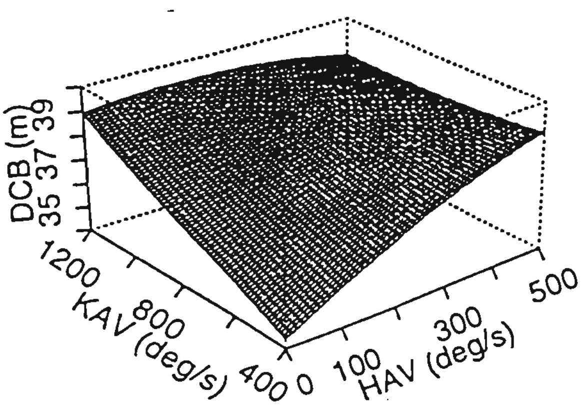
Figure 4.5.6.2.3 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 30°



(a) Contour plot showing the relationship between HAV and KAV for various DCB's

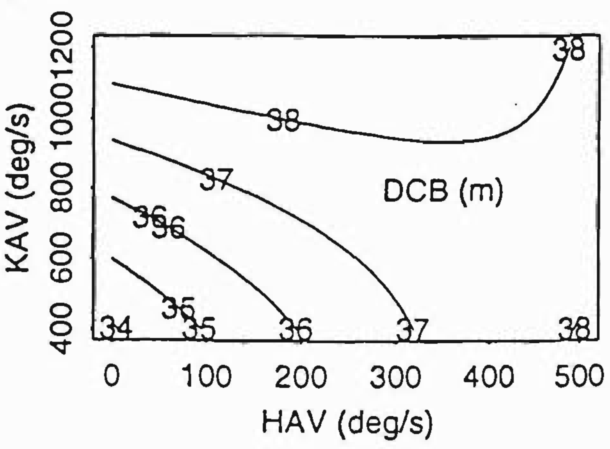


(b) Plot showing the relationship between DCB and KAV for different HAV

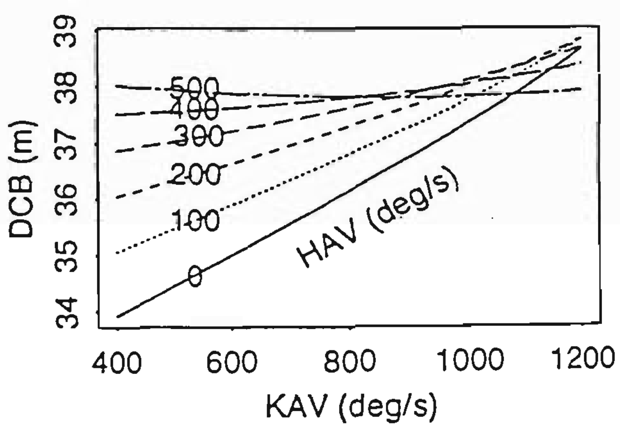


(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

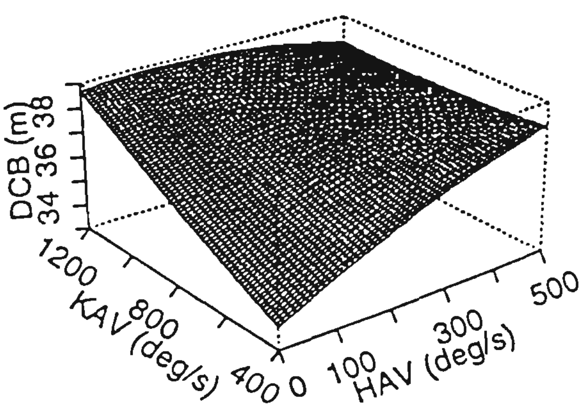
Figure 4.5.6.2.4 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 45°



(a) Contour plot showing the relationship between HAV and KAV for various DCB's

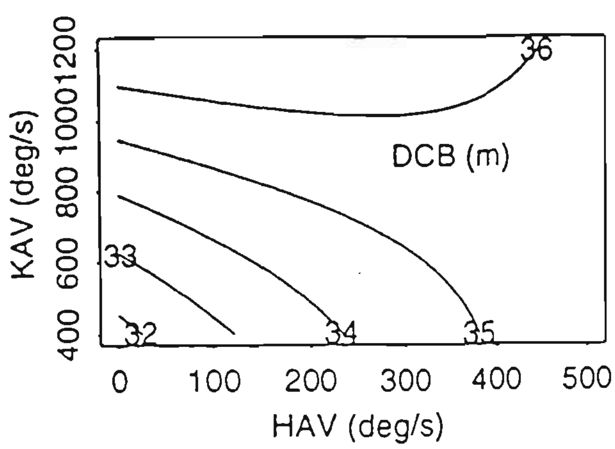


(b) Plot showing the relationship between DCB and KAV for different HAV

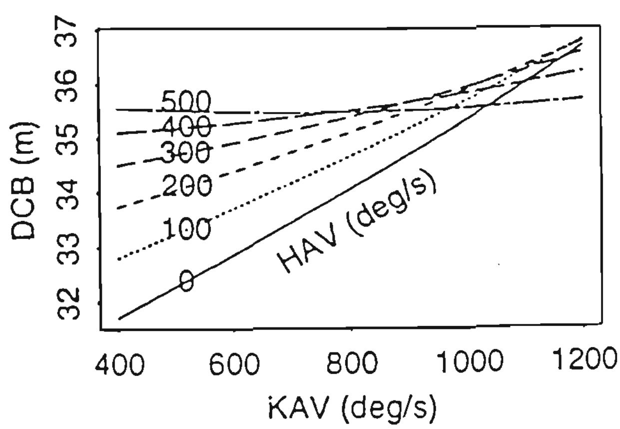


(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

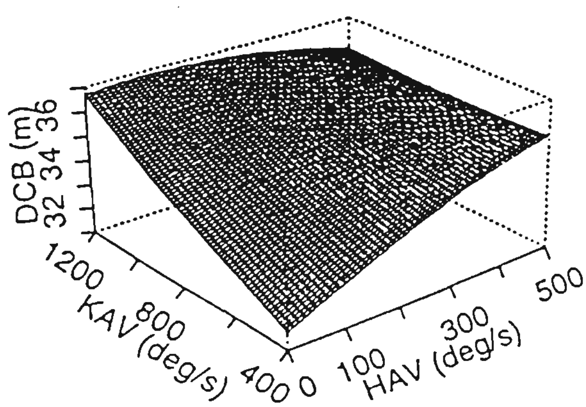
Figure 4.5.6.2.5 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 60°



(a) Contour plot showing the relationship between HAV and KAV for various DCB's

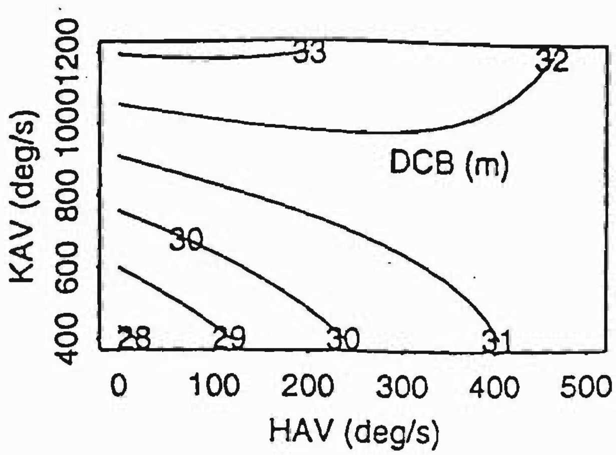


(b) Plot showing the relationship between DCB and KAV for different HAV

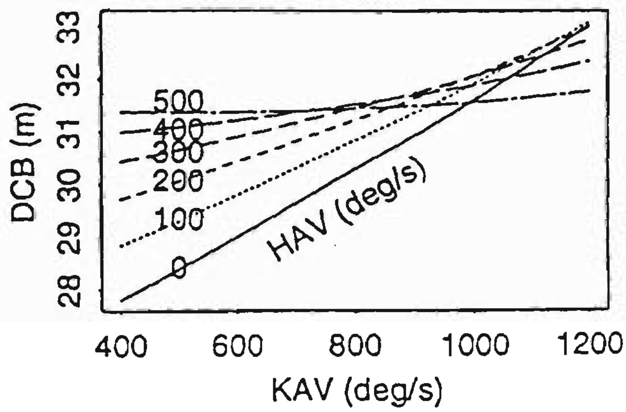


(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

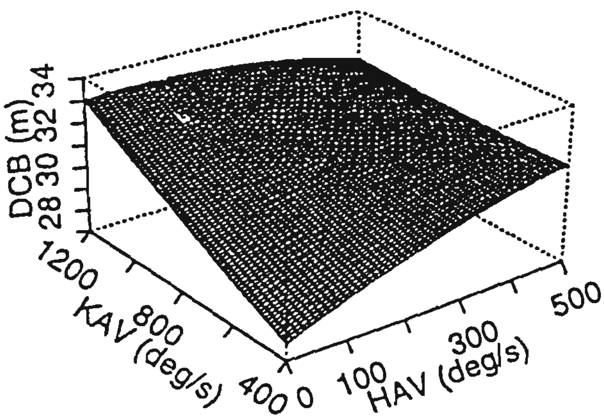
Figure 4.5.6.2.6 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 75°



(a) Contour plot showing the relationship between HAV and KAV for various DCB's



(b) Plot showing the relationship between DCB and KAV for different HAV



(c) 3-Dimensional plot showing the relationship among HAV, KAV and DCB

Figure 4.5.6.2.7 Various Plots Showing the Relationship Among DCB, KAV and HAV for an Approach Angle of 90°

4.6 EXAMINATION AND SUMMARY OF THE HYPOTHESES

As per the design of the present study investigation of fourteen hypotheses were required (see section 1.5). Hypothesis number one to twelve were tested using ANOVA. Statistical analyses of these data are presented in the results section suggest that except the hypotheses of 5 and 10 all other hypotheses were rejected at 0.05. Rejection of the null hypothesis indicates that there were significant effects of AA on number of kinematic variables. The hypothsis number thirteen and fourteen were tested by applying stepwise regression analysis and found that except linear velocity of toe (LVT) rest of the linear velocities of kinematic variables (hip, knee, ankle, heel and body COM) were non-significant to the cause of DCB. Similarly except ankle angular velocity hip and knee were significant thereby rejecting the null hypothesis. Based on the results of this study, the following conclusion can be drawn on the hypotheses.

1. There is a significant effect of the AA on DCB. REJECTED.
2. There is a significant effect of the AA on AC of the kick. REJECTED.
3. There is a significant effect of AA on LVH. REJECTED.
4. There is a significant effect of AA on LVK. REJECTED.
5. There is no significant effect of AA on LVA. ACCEPTED.
6. There is a significant effect of AA on LVHE. REJECTED.
7. There is a significant effect of AA on LVT. REJECTED.
8. There is a significant effect of AA on the linear velocities of COM of whole body. REJECTED.

9. There is a significant effect of AA on LVB. REJECTED.

10. There is no significant effect of AA on HAV. ACCEPTED.

11. There is a significant effect of AA on KAV. REJECTED.

12. There is a significant effect of AA on AAV. REJECTED.

13. There is a significant effect LVT on DCB. REJECTED.

14. There is a significant effect of HAV on DCB. REJECTED.

15. There is a significant effect of KAV on DCB. REJECTED.

Chapter v

DISCUSSION OF RESULTS

The objective of the study was to investigate the kinematics of instep kick in soccer and to determine the effect of approach angle (AA) variations on two major outcome variables e.g. distance covered by the ball (DCB) and an accuracy of the kick (AC). Specifically, this study examined the effect of AA on linear and angular velocities of major joints of the kicking limb that play an important role in instep kick. Investigation of the effect of linear and angular velocities of the lower limb on DCB while executing the instep kick from different AA was also carried out, to find out which biomechanical variable (s) contribute significantly to the distance travelled by the ball.

The finding of results are discussed in this chapter and addressed in the following sequence:

(i) Kinematics of instep kicking motion

(ii) Effect of AA on DCB

(iii) Effect of AA on accuracy of the kick

(iv) Analysis of kinematic variables:

(a) Linear velocities of hip, knee and ankle joints of the kicking limb

(b) Linear velocities of heel and toe of the kicking limb

(c) Linear velocity of the body centre of mass (COM)

(d) Linear velocity of ball

(e) Angular velocities of hip, knee and ankle joints of the kicking limb

(f) Effect of linear velocities of kicking limb and body COM on DCB

(g) Effect of angular velocities of kicking limb on DCB

(v) Conclusion

(vi) Recommendation for future research

5.1 KINEMATICS OF INSTEP KICKING MOTION

In the present study the sequence of the kicking motion has been divided into four phases according to Brown and Williamson (1991): (a) Approach (ground contact of the kicking foot to ground contact of the non-kicking foot along side the ball); (b) Pre-Impact (ground contact of the non-kicking foot to before contact of ball with the kicking foot); (c) Impact (ball contact with the kicking foot) and (d) Follow-through (ball contact/ strike to ball take-off). However, various investigators have divided the kicking motion into a varying number of phases and events. For example DeProft et al. (1988) divided the kicking motion into six phases, where as Luhtanen (1988) and Tant (1990), have suggested only three phases. In the present study ground contact of the kicking foot (KFC) was selected as the beginning of the kicking motion. Ground contact with the non-kicking foot (NKFC) and before contact of the ball (BBC)) with the kicking foot were identified as the part of the Pre-Impact phase. The impact phase: ball contact

(BC) and follow-through phase of ball take-off (BTO) were selected as the ending of the kicking motion.

In order to examine the motion sequences of the instep kick a typical subject was selected to study the 3-D angular motion of hip, knee and ankle. Though this subject has showed a slight variation in the rang of hip motion but failed to exhibit major differences in the pattern of the hip angle displacement, while kicks were taken from the different approach angles. Graphic representation (Figures 4.2.1- 4.2.7) indicated a high extension of hip in the initial leap in the approach phase and flexed through BC. Several investigators such as Robert and Metcalf (1968); Copper et al. (1982); Levanon and Dapena (1998) described that the hip action makes a substantial contribution in the early force-producing phase. As the thigh was swung forward by hip flexion, it carries the leg and foot with it, which helps in generating a high velocity in the other parts of the kicking limb. They along with Huang et al. (1982) and Tant (1990) illustrated that the hip began in an extended position in the initial stage and flexed through to BC. However it is not clear from these studies, at what approach angle the kick was taken. In terms of pattern of the displacement of the hip the findings of the present study were consistent with these literature. During this study the maximum extension (162°) and flexion (83°) of the hip, was noted while kick, was executed from the approach angle of 90°. This may be due to the fact that 90° to the approach direction of the step involves more hip joint angular execution compared to other AAs in order to kick the ball further.

Figures 4.2.1.-4.2.7 suggested that although there were slight variations in the magnitude of knee angles from one AA to another AA, the overall pattern of the knee motion was similar. The moment kicking foot take-off the ground knee began to have an action of flexion-extension movement and then again flexes to its maximum before it starts extending prior to BBC. The continuation of the knee extension remains intake until it passes through to follow-through phase. Investigations carried out by Plangenhoef (1971), Abo-Abo (1979), Tant (1990) and Levanon and Dapena (1998) have also reported that maximum flexion of the knee occurred prior to ball contact followed by rapid extension till the follow-through phase.

At the beginning of the kicking motion, ankle was seen to undergo the plantarflexion followed by a sharp dorsiflexion movement during the approach phase. This was observed for all the kicks taken from the different approach angles (see Figures 4.2.1. - 4.2.7). During this period (approach phase) the maximum and minimum plantar flexion of the ankle for this subject was noted while the kicks were taken form the approach angle of 0° (130°) and 90° (106°) respectively. As the motion of the kicks passed through the approach phase ankle once again began plantarflexing until it reached follow-through phase. This angular motion of the ankle was observed in the kick executed from all the AAs. The maximum and minimum dorsiflexion of the ankle was observed while kick was taken from the approach angle of 90° (53°) and 0° (82°) respectively and this was occurred during the approach phase of the kick. Lees (1996) in his investigation reported that in kicking large impact of foot with the ball serves to forcefully plantarflexing the ankle and it will do so until the bones at the ankle joint reach their extreme range of motion. Levanon and Dapena (1998) found a motion of planatarflexion of the ankle joint between the take-off and BC. This phenomenon was not evident in this subject, perhaps due to individual differences of subject and also different design of experiment.

The approach angles within 45° - 75° produced the maximum angular velocity of the hip (see Figures 4.2.11 – 4.2.13) for this subject when hip was extended to its maximum during "Approach" phase. Interesting to note that the angular velocity of the knee attained maximum at BC for the AA of 15° and 30°. The study carried out by Putnam (1981, 1983) Huang et al., (1982) and Tant (1990) also reported that maximum knee angular velocity occurred at BC. The results of this subject also suggest that for the AA of 45° to 90° and 0° maximum angular velocity of the knee occurred either before or after BC. The maximum angular velocity of the ankle angle in the present study was found for the AA of 90° at BTO (Figure 4.2.14). Most of the AA has shown different maximum angular velocity of the ankle angle at different periods/ phases of the kick however it has been observed that these maximum angular velocity was produced while ankle was in the process of plantarflexing. However, no relevant literature was found relating to the angular velocity of the ankle joint while kick was executed from different AAs. Tant (1990) has supported the principle of the transfer of momentum, which implies that if the angular velocity of the thigh is decreased, the angular velocity of the lower leg will increase. It was observed in the present study that at the time of BC the angular velocity of the hip for all the AA was noted less in comparison with the velocity of the knee (Figure 4.2.8-4.2.14).

5.2 EFFECT OF APPROACH ANGLES ON DISTANCE COVERED BY THE BALL

The present study has revealed that the approach angle in the execution of instep-kick is very important in determining the maximum distance covered by the ball. The optimum distance covered by the ball was found while kicks were taken from the approach angles of 30°-60°. The approach angle of 45° produced the maximum distance of about 39m for the group and 0° produced the minimum distance of about 29 m (Basumatary et al., 1990). There was significant differences for distance covered by the ball across the range of approach angles (Appendix D, Table 1). Specifically 0°, 45° and 90° approach angles were significantly different than the rest of the approach angles. Cooper et al. (1982) reported that distance travelled by the ball mainly depends on two factors: the velocity of force as it strikes the ball and the angle of release. They stated that a high horizontal velocity and a low angle of release (40°) will cause the ball to travel a longer distance. Colfer and Dowell (1977) also reported that mean angle of projection for a kick should be lower than the theoretical optimum angle of projection of 45 degree. The results (see Figure 4.3.1; Table 4.3.1) of the effect of the approach angle on ball velocity indicated that AA in between the 30° to 60° produced high velocity of the ball, which is also supported by Isokawa and Lees (1988). The Figure 4.3.1 shows the effect of the AA on DCB, which is similar to the LVB (Figure 4.5.4.1). Perhaps, this strong relationship between the LVB and DCB might have contributed to project the ball to a maximum distance for approach angles between 30° to 60°.

5.3 EFFECT OF APPROACH ANGLES ON ACCURACY OF THE KICK

An accuracy of the kick in the game of soccer is most important while scoring a goal or passing a ball to team members. So far no investigation on the influence of approach angles on an accuracy of the instep kick been reported. The results (see Table 4.3.2) of the present study revealed that AA significantly affected accuracy of the kick ($F=79.63$, $p<0.0001$). The highest accuracy was found at an approach of 45° (M= 0.92 m) which was significantly different from the rest of the approach angles but insignificantly different from the approach angle of 60°. The approach angles of 30° (M=1.56m) and 60° (M=1.42m) also exhibited good accuracy of the kick and insignificantly different from each other but significantly different from the other approach angles (0°, 15°, 45°, 75° and 90°). The results (Figure 4.4.1) indicate that the accuracy of the kick was reduced as the approach angles were widening from 45° angle. The minimum accuracy was found while kicks were taken from 0°(M=4.11m) approach angle which was significantly different from all other approach angles. The results demonstrated that 45° approach angle provides both maximum accuracy and maximum DCB. It has been reported by Plgenhoef (1971) that the placement of the non-kicking foot at the time of kicking plays an important role in successful kick. It should be placed in such way that it provides the best fit of the kicking foot to the ball. It was revealed that because of the round shape of the soccer ball contact of the foot with the ball is more firm when kicking in executed from the side approach than the straight approach. Ahrari (1981) also reported that greatest accuracy is produced when instep kick is executed from an angled approach. Consistent with this finding, the current investigation also highlights the importance of angled approach in the success of kick with maximum accuracy for 45° AA.

5.4 ANALYSIS OF KINEMATIC VARIABLES

5.4.1 Linear velocities of hip, knee and ankle joints of the kicking limb

The ANOVA results (see Table 4.3.2)) reveals that approach angle have a significant effect on linear velocity of hip at ball contact (BC). The linear velocity of the hip (LVH) was highest while kick was taken along the direction of the motion from an approach angle of 0° and as the approach angle increased the LVH also gradually decreased. The pattern of this decrease in LVH was also noted in the study carried out by Isokawa and Lees (1988). The notable difference was that instead of investigating the velocity at BC, the velocity was examined when it was peak during the approach phase. Further in their investigation approach angle of 15° produced the maximum velocity (M=3.13m/s). In the present study highest velocity at BC was found at an approach angle of 0° (M=1.56 m/s). This minute difference in this finding might perhaps because of the examination undertaken at different events. The Bonferroni post hoc test (Appendix D, Table 3) showed that except 15° all other AAs were significantly different from 0° AA which produced maximum LVH at BC.

The result of the investigation (Figure 4.3.2) on the effect of approach angles on linear velocity of knee (LVK) has revealed that approach angles are also very important in generating a maximum linear velocity at knee. There exists a significant effect of AA on LVK. The maximum velocity (M= 3.27 m/sec.) was found while kick was executed from the AA of 30°. The notable observation was that as the AA increases or decreases from the AA 30° the linear velocity of the knee decreases gradually (see Figure 4.5.1.2.1). The lowest velocity was produced at an AA of 90° (M=2.46 m/s). The Post hoc test (Appendix D, Table 4) showed that the approach angle of 90° was significantly different from rest of the approach angles. In the study conducted by Isokawa and Lees (1988), the peak velocity was recorded at an AA of 0° (M= 7.36 m/ sec) and as the approach angles increases the gradual decrease of the velocity of the knee was observed. As mentioned before, they reported peak knee velocity regardless of any events/ phases. In the current investigation, however, the knee velocity at the important event of BC has been examined. This might have contributed to varying results between these studies. It should also be noted that Isokawa and Lees (1988) carried out a 2-D analysis that fails to accurately record the complex 3-D motion of soccer kick.

The findings of the study (see Table 4.3.2) suggested non-significant effect of the AA on linear velocity of ankle (LVA). The LVA was found to be maximum when kick was executed from the AA of 30° (M= 10.73 m/ sec) and minimum when it was taken from the AA of 90° (M=9.94 m/s). Isokawa and Lees (1988) also reported the same pattern of LVA with reduced magnitude. However these maximum velocities were noted just before ball contact (BBC) whereas the present investigation was concentrated at the time of BC.

5.4.2 Linear velocities of heel and toe of the kicking foot limb

It was observed from ANOVA tests (Table 4.3.2) that approach angle (AA) had significant effects on both linear velocity of toe (LVT) and heel (marginal) at BC. The highest linear velocity of the heel was noted while kick was executed from the AA of 15° (M=11.91m/s) and lowest being at 90°(M=11.19m/s). The author failed to find any relevant literature to compare these findings. Perhaps it is considered as least important in the execution of successful instep kick, since major contribution of the velocities of the kicking limb comes from other joints.

The maximum LVT was found at an AA of 30°and 45° and highest being recorded at an AA of 30° (M=13.74m/s). Interestingly, it has been noted that velocity of the toe gradually decreased as the AAs were shifted from 30°. The study conducted by Isokawa and Lees (1988) had also reported relatively higher toe velocity at an AA of 30° (M=18.32m/s) which was reported to be generated just before BC. It is not know from this study how LVT was affected at the time of BC.

5.4.3 Linear velocity of the body centre of mass (COM)

How the centre of mass of the whole body of the soccer players behaves in the execution of a correct instep kick is yet to be discovered. Specifically, how approach angle influence COM dynamic velocities during a soccer kick has not been explored before. The present study provided very interesting results about COM while kicks were performed from different approach angles. It is interesting to note that COM velocity remains fairly constant (M = 1.91 m/s) up to 45° approach angle (see Figure 4.5.3.1) and following that there is a sharp decrease in COM velocity. The post hoc test presented in appendix D, Table 7 also highlights that COM velocities during 0° to 45° AAs are significantly different from the rest of AA (60° to 90°). These results indicate that the total body momentum would be fairly invariant for AAs of 0° – 45°. However, for AA > 45°, the momentum of the body would be significantly decreased along the direction of target.

5.4.4 Linear velocity of ball

The findings of the present investigation (Figure 4.5.4.1) suggest that the approach angle play a very important role in determining the velocity of the ball. The results revealed that AAs significantly affects linear velocity of the ball (LVB). The maximum LVB was observed between the AAs of 30°-60° and highest being noted at an AA of 45° (M=18.61m/s). From the post hoc test (Appendix D, Table 8) it was observed that the velocity generated at 45° AA was significantly different from velocities generated at other AAs. On the other hand, this research has also suggested that AA of 0° which has generated minimum ball velocity (M=14.92 m/s) was also significantly different from the rest of AAs. It is evident from the Figure 4.3.1 and Figure 4.5.4.1 that distance covered by the ball (DCB) and LVB are identically affected by AAs. This shows strong relationship between linear velocity of ball and distance travelled during a soccer kick.

The above findings regarding ball velocity can be supported by a limited number of studies that have examined the effect of AA on ball velocities. A number of investigators (Moudgil, 1967; Plagenhoef, 1971; Asai et al. 1980), reported higher ball velocity for angled approach compared to a straight instep kick. Isokawa and Lees (1988) who finally examined the influence of different AA (0°, 15°, 30°, 45°, 60° and 90°) on ball velocity reported that AA within the range of 30°-60° generated higher ball velocity, with a maximum velocity at 45°(M=20.14 m/s). The findings of the present study support the investigation done by Isokawa and Lees that the AAs between 30° - 60° generate maximum ball velocity, although the actual magnitudes of ball velocity in their study were slightly higher than those presented here.

5.4.5 Angular velocities of hip, knee and ankle joints of the kicking limb

The present investigation shows (see Table 4.3.2) that among the 3-D angular velocities at BC only knee angular velocity (KAV) was significantly affected by AA. Angular velocity of ankle (AAV) also showed marginal significance. The HAV was found maximum at the AA of 45°(M= 201.85 deg/s). The AAs between the 0°-30° yielded maximum KAV and highest being at 0° (M= 819.18 deg/s). The highest AAV was observed in between the AAs of 45°- 90° and the maximum was found at 90° (M=532.98 deg/s). As the AA increases from 45°-90° the AAV also been observed increasing gradually. The results (Figures 4.5.5.1.1 – 4.5.5.3.1) suggest that AA can affect the 3-D angular velocities of hip, knee and ankle joints at BC during a soccer kick. These varying 3-D knee and hip angular velocities have the potential to affect distance covered by the ball as discussed in section 5.4.7. However, it will also be interesting to investigate these angular velocities projected on 2-D planes such as in the plane of activity.

5.4.6 Effect of linear velocities of kicking limb and body centre of mass on DCB

The results of stepwise regression analysis presented in section 4.5.6 suggest that the linear velocity of toe (LVT) plays an important role in performing a maximum distance kick. The finding also revealed the importance of AAs in generating maximum velocity at toe, which ultimately help in the performance of the kick. The other variables such as linear velocities of hip, knee, heel, ankle and COM were not significant contributors. The adjusted r square value suggested that 87% of variance in the distance covered by the ball could be attributed to LVT. The results presented in Figure 4.5.6.1.1 depicted the 3-D relationship among the AAs, LVT and distance covered by the ball (DCB). It has been observed from this figure that in order to increase the DCB the velocity of the toe is to be increased. The LVT was recorded maximum while kick was taken from the AA of 30° - 45°(Figure 4.5.2.2.1). It was also observed that the LVT was found minimum while kick was taken from the approach angle of 0°. As the approach angles were moved away form the 0° the LVT was noted increasing gradually and attained maximum at 30° (M= 13.74m/s). Thereafter the LVT dropped gradually as the approach angle increased further from 30°. This effect of AA on LVT has been described in detail in section 5.4.2. Interesting to note that the maximum distance covered by the ball was also recorded while kicks were taken from the approach angles of 30°- 60° and highest being at 45° (M= 39.01m). The results suggest that the distance covered by the ball is dependent on the LVT and in order to generate more linear toe velocity one needs to consider the approach angle also. Various plots in Figure 4.5.6.1.1 describe this combined effect of LVT and AA on DCB.

5.4.7 Effect of angular velocities of kicking limb on DCB

The angular velocities that have been investigated to find out their effects on distance covered by the ball (DCB) were hip, knee and ankle joints. To pick up which one of these variable makes a useful contribution to the overall prediction a stepwise multiple regression analysis was applied. Result of this analysis showed that only hip ($t=3.21$; $p<0.002$) and knee ($t=2.82$, $p=0.006$) angular velocities have significantly contributed to the cause of DCB. The regression equations suggest that 89% and 90% of variance in the DCB can be attributed to hip and knee joint angular velocities respectively. The Figures 4.5.6.2.1 – 4.5.6.2.7 show the relationship among angular velocities of hip, knee, approach angles (0° to 90° instep of 15°) and DCB. An interesting finding was that consistency of DCB was observed when the angular velocity of the knee (KAV) was increased in comparison to hip angular velocity (HAV). This has been noted in all the kicks taken from the different approach angles. The findings of the result also revealed that though the KAV was recorded highest at an AA of 0° (M= 819.18 deg/s) the maximum DCB was noted while kick was taken from the AA of 45° (M=39.01m). However the HAV was observed highest while kick was taken from 45° (M=201.85

deg/s). The major conclusion was that the predicted DCB increases roughly linearly with HAV when KAV was small, while DCB does not depend much on HAV when KAV was large. Similarly DCB increases linearly with KAV for low HAV but for higher HAV, the effect is minimal. However these effects on DCB depend on AA with maximum DCB occurring at 45°. Since no literature was found regarding the relationship among the approach angles, angular velocities of lower limb joints and distance covered by the ball, therefore conclusions to the present finding remain to be established.

5.5 CONCLUSIONS

Considering the scope and the limitations of this study the following conclusions were drawn from the investigation:

1. Approach angles has an important role to play while instep kick is being taken to cover a maximum distance. The approach angles of 30° to 60° were found to cover maximum distance of the ball.
2. In order to maintain maximum accuracy of the instep kick, soccer player should execute the kick from the AA of 30° to 60°. Highest accuracy was found for approach angle of 45°.
3. Approach angles has significant effect on linear velocity of hip, knee, toe, centre of mass of whole body, ball and angular velocities of the knee and ankle.
4. Approach angle of 30° to 60° yielded maximum linear velocity of ball at ball take-off.
5. Linear velocity of centre of mass remained fairly constant up to 45° approach angle, after that it decreased abruptly suggesting a reduction of linear momentum of the body along the direction of kick for approach angle > 45°.
6. Linear velocity of the toe has been a significant contributor to the cause of distance covered by the ball for all approach angles.
7. Angular velocity of the hip and knee both significantly contributed to the cause of distance covered by the ball.

8. The predicted distance covered by the ball increases roughly linearly with angular velocity of hip when angular velocity of the knee was small, while DCB does not depend much on HAV when KAV was large. Similarly DCB increases linearly with KAV for low HAV but for higher HAV the effect is minimal.
9. For a particular DCB, an increase in angular velocity of knee causes a decrease in the angular velocity of the hip and vice versa, in the execution of successful instep kick.

5.6 RECOMMENDATION FOR FUTURE RESEARCH

Based on the findings of the present investigation, the following recommendations are made for further research:

1. Examine the influence of the approach angles on kinetic parameters (e.g. Joint forces, joint moments) of the kicking as well as non-kicking leg.
2. Examine the relationship among approach angles, kinetic parameters, distance covered by the ball and accuracy of the kick.
3. Use of force platform and electromyography in combination with kinematic data to aid in better understanding of the patterns of the movement and muscle activation in a kicking motion and how different approach angles affect these results.
4. Repeat the present study with different population groups to examine gender and age effects at different skill levels (skilled and unskilled). This would provide invariant parameters for a kicking motion.
5. A similar study may be conducted to investigate upper body kinematics due to approach angle variations and also using high speed video cameras for better identification of ball contact.

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APPENDICES

Consent Form

Score Sheet

Raw Data

Post-hoc Test Table

Appendix A

VICTORIA UNIVERSITY OF TECHNOLOGY

STANDARD CONSENT FORM FOR SUBJECTS INVOLVED IN EXPERIMENT

CERTIFICATION BY SUBJECT

I,...
of...
certify that I have the legal ability to give valid consent and that I am voluntarily giving my consent to participate in the experiment entitled:

"..
...."

being conducted at Victoria University of Technology by:

....

I certify that the objectives of the experiment, together with any risks to me associated with the procedures listed hereunder to be carried out in the experiment, have been fully explained to me:

....

and that I freely consent to participation involving the use on me of these procedures.

Procedures

....
....

I certify that I have had the opportunity to have my questions answered and that I understand that I can withdraw from this experiment at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the confidentiality of the information I provide will be safeguarded.

Signed:..

Witness other than the experimenter: Date.......................

....

Appendix B

SCORE SHEET

Measurement of Distance Covered by the Ball and an Accuracy of the kick

Sl. No... Name of the Subject.......................................Date of Birth...........

Trial No.	Approach Angle													
	0 Degree		15 Degree		30 Degree		45 Degree		60 Degree		75 Degree		90 Degree	
	dcb (m)	ack (m)	dcb (m)	ack (m)	dcb (m)	ack (m)	dcb (m)	ack (m)	dcb (m)	ack (m)	dcb (m)	ack (m)	dcb (m)	ack (m)
One														
Two														
Three														

Anthropometric Measurements:

1. Body Mass..............kg
2. Stature....................m
3. Thigh Length.............m
4. Lower Leg Length........m
5. Ankle Height..............m

Wind Velocity................m/s

Weather Temperature.........Degree Celsius

Signature of the Investigator...................... Date........... Time............

Appendix C

Raw Data's of Distance Covered by the Ball (BCB)

Subject	DCB1	DCB2	DCB3	DCB4	DCB5	DCB6	DCB7
1	30.40	34.90	37.51	38.67	36.60	35.60	29.50
2	27.15	30.00	31.40	31.85	29.90	29.30	28.20
3	26.62	32.05	33.55	34.00	31.80	29.05	25.75
4	25.50	28.94	29.50	31.45	30.15	28.80	27.60
5	29.43	32.39	35.43	36.87	34.46	35.19	28.13
6	21.66	24.70	29.66	31.00	28.70	25.30	22.80
7	24.69	28.34	30.14	39.24	36.22	29.33	28.85
8	26.36	30.90	31.55	35.60	34.65	32.75	28.85
9	29.22	34.28	39.32	41.40	40.49	31.00	29.70
10	30.46	33.31	34.57	38.39	36.34	36.50	33.00
11	24.30	29.50	32.00	33.90	30.50	29.30	27.00
12	32.40	36.46	39.80	45.35	39.21	40.10	38.39
13	28.90	29.27	38.40	43.55	39.26	38.10	32.60
14	28.20	30.90	34.86	42.10	38.35	30.15	29.10
15	32.00	36.30	39.40	45.15	39.15	38.10	34.20
16	29.52	34.09	36.30	38.35	36.85	33.42	31.06
17	34.52	40.66	42.55	45.86	42.35	39.56	38.90
18	33.87	39.29	40.30	42.78	41.62	37.50	32.82
19	32.93	34.60	39.82	42.38	40.25	35.45	29.37
20	30.32	36.90	37.36	42.38	41.64	39.20	37.16

Raw Data's of an Accuracy of the Kick (ACK)

Subject	ACK1	ACK2	ACK3	ACK4	ACK5	ACK6	ACK7
1	4.5	2.2	1.3	0.22	0.39	2.8	3.5
2	3.74	2.2	1.7	0.97	1.5	1.98	2.65
3	5.13	3.1	0.93	0.85	1.55	1.6	3.5
4	7.5	6.53	3.25	2.4	3.45	4.5	5.3
5	4.42	4	0.94	0.7	0.4	2.5	4
6	3.37	2.5	1.27	1.1	1.7	2.1	3.1
7	3.38	3.08	1.12	0.95	1	2.95	3
8	3.85	3.4	2.45	1.15	1.2	2.23	3.05
9	6	5.3	1.3	1.1	2.45	2.6	3.45
10	3.44	2.45	0.3	0.55	1.56	2.66	3
11	4	2.67	2.3	0.3	0.8	1.3	3.15
12	5.13	2.39	1.48	0.85	1.05	2.15	3.06
13	2.8	2.1	1.98	0.79	1.25	1.99	2.4
14	4.25	3.02	2.06	1	1.15	2.98	3.1
15	4.1	2.2	1.28	0.97	1	2.05	3.1
16	3.62	2.35	1.58	0.99	1.05	2.4	3.01
17	2.32	2.02	1.44	0.9	1.79	2	2.15
18	4.39	2.71	1.97	1	1.75	2.05	3.4
19	2.72	2	1.07	0.95	1.96	2.11	2.41
20	3.5	2.88	1.41	0.57	1.41	2.19	3.86

Appendix C (continued)

Raw Data's of Linear Velocity of Hip (LVH)

Subject	LVH1	LVH2	LVH3	LVH4	LVH5	LVH6	LVH7
1	0.816	1.832	0.906	1.595	0.44	0.588	0.485
2	2.118	1.126	0.928	0.751	0.054	0.32	0.35
3	2.525	1.835	1.885	1.581	0.731	0.61	0.107
4	1.871	1.5	1.82	1.747	0.906	0.444	0.239
5	1.697	1.955	2.427	1.774	1.125	0.379	0.365
6	1.841	1.827	1.016	1.345	0.789	0.447	0.346
7	1.076	0.6	0.904	1.123	0.628	0.516	0.269
8	1.138	0.998	0.886	0.562	0.39	0.183	0.165
9	1.754	1.201	1.411	1.247	0.73	0.463	0.53
10	1.525	2.069	1.589	1.409	0.51	0.43	1.039
11	0.778	1.349	1.182	0.5	0.661	0.099	0.342
12	1.553	1.424	1.307	0.779	0.789	0.07	0.643
13	2.079	1.18	1.224	1.041	0.67	0.44	0.046
14	1.805	1.413	1.38	0.568	0.648	0.467	0.238
15	1.575	1.518	1.314	0.897	0.746	0.422	0.774
16	1.968	1.316	0.909	0.789	0.377	0.271	0.071
17	0.99	1.175	1.552	0.674	0.648	0.231	0.148
18	1.44	1.025	0.824	0.853	0.414	0.553	0.294
19	1.26	1.282	1.093	1.047	0.389	0.051	0.059
20	1.406	1.129	0.971	1.115	0.571	0.252	0.333

Raw Data's of Linear Velocity of Knee (LVK)

Subject	LVK1	LVK2	LVK3	LVK4	LVK5	LVK6	LVK7
1	1.585	2.53	1.648	3.206	1.981	2.977	2.105
2	3.077	3.448	2.841	3.048	1.872	2.785	2.88
3	3.03	2.859	3.311	3.046	2.796	2.487	1.906
4	3.445	2.743	3.304	3.132	2.977	2.809	2.5
5	2.976	3.597	4.476	4.025	4.109	3.88	2.845
6	2.7	2.548	2.779	2.96	2.708	1.805	1.116
7	2.761	2.704	3.005	3.689	3.341	3.368	2.757
8	3.2	4.508	3.206	3.165	2.747	2.649	1.761
9	2.814	2.498	3.675	2.926	3.069	3.085	2.809
10	2.18	3.171	2.813	2.109	2.683	1.822	1.105
11	0.479	2.196	1.869	2.348	1.786	2.096	2.182
12	2.979	3.909	3.873	3.352	3.565	3.428	2.528
13	4.099	3.561	3.716	3.844	3.136	2.777	2.643
14	3.556	3.087	3.799	3.164	3.681	3.632	3.518
15	2.697	3.445	3.699	3.448	3.536	3.398	2.299
16	3.669	3.539	3.555	2.965	2.874	2.93	2.539
17	3.223	3.505	4.008	3.395	3.338	3.157	2.689
18	2.835	2.824	3.147	3.208	3.135	3.119	3.192
19	3.214	3.811	3.774	3.95	2.97	3.004	2.66
20	2.84	2.929	2.934	2.943	3.397	3.086	3.196

Appendix C (continued)

Raw Data's of Linear Velocity Ankle (LVA)

Subject	LVA1	LVA2	LVA3	LVA4	LVA5	LVA6	LVA7
1	9.1831	10.6945	9.8926	10.7121	10.4768	11.8124	11.6476
2	9.3276	10.2875	9.5107	10.5796	9.2567	10.183	8.443
3	9.9699	10.1952	11.1637	11.3394	10.1007	9.9806	10.3205
4	10.8133	10.4276	10.1382	9.0582	10.4729	9.68	9.312
5	10.7436	11.2027	12.4694	12.0806	10.8111	10.7656	9.165
6	9.4722	9.90558	10.1537	10.8747	9.497	9.232	8.554
7	10.0501	10.1161	10.3988	11.2667	11.522	10.6056	9.6762
8	10.9743	10.3546	9.5882	8.7119	8.765	10.0109	8.124
9	9.7883	10.3106	11.1916	11.2891	10.7509	9.7386	10.1864
10	9.2714	11.7608	12.0062	10.6009	10.6931	10.1513	9.652
11	7.788	3.264	8.37	8.482	8.959	8.659	8.619
12	10.0204	11.7419	11.5783	10.5894	9.8029	10.9392	10.2178
13	11.6151	11.098	11.5942	12.018	10.0134	10.8152	9.875
14	11.4417	10.4814	11.5681	10.6806	10.8626	11.1986	11.2356
15	9.894	11.1954	11.4099	10.6032	10.8621	11.4135	10.3976
16	11.4471	11.1226	11.557	9.6194	11.464	10.9727	10.3646
17	9.734	10.7418	10.7227	10.2294	11.3068	11.0697	10.8633
18	10.7353	9.7729	10.0633	9.7592	11.2519	11.0692	11.1845
19	10.7499	11.3182	11.6936	11.0318	10.9315	10.7583	10.3014
20	10.8379	9.7982	9.5839	9.7991	10.0214	10.6203	10.6601

Raw Data's of Linear Velocity of Heel (LVHE)

Subject	LVHE1	LVHE2	LVHE3	LVHE4	LVHE5	LVHE6	LVHE7
1	12.2626	12.1364	11.7312	12.3099	12.375	12.4931	12.1752
2	10.9626	12.3954	11.2104	10.8695	10.9623	10.463	10.3648
3	12.2823	12.3686	12.3409	12.9233	11.6858	11.6432	13.0603
4	12.5389	11.2764	11.712	10.5291	10.126	10.727	9.183
5	10.7436	12.8043	12.4894	12.0806	10.8111	10.7656	9.165
6	11.3459	11.3345	9.4219	11.8178	10.5385	9.776	9.5547
7	11.9621	10.3658	12.1619	12.6219	13.1365	11.9389	10.87
8	13.3437	11.7625	10.9827	10.0386	9.663	11.3249	10.2891
9	11.7431	11.6986	11.6976	11.3276	11.1475	11.1432	11.6114
10	11.0533	13.2036	12.2265	12.2001	11.9414	10.8587	11.507
11	9.9375	9.689	9.252	10.2478	10.0069	10.2901	9.632
12	11.146	12.0811	13.0448	11.3646	11.3688	12.8566	12.598
13	13.0264	12.524	12.9361	12.2483	11.0617	12.1228	11.0551
14	12.412	11.2241	12.6406	12.0719	12.7954	12.3077	12.6675
15	11.3406	12.4584	13.2936	12.2295	11.8728	12.4341	11.681
16	13.1042	12.6107	12.9058	11.2349	10.7407	12.5169	11.654
17	10.5612	11.9945	12.2397	11.8041	12.7556	8.569	11.9424
18	13.1239	11.3566	11.7848	11.0779	10.9274	12.3621	11.7727
19	11.4839	12.8925	12.5162	12.5443	12.7559	12.0547	12.0041
20	11.7106	12.0094	10.8392	11.6153	11.9887	12.1384	10.9945

Appendix C (continued)

Raw Data's of Linear Velocity of Toe (LVT)

Subject	LVT1	LVT2	LVT3	LVT4	LVT5	LVT6	LVT7
1	10.6434	12.799	11.4485	14.5222	13.4418	14.7874	13.8435
2	13.7786	14.593	13.6121	13.4535	12.2558	14.2218	12.662
3	12.5994	12.5247	14.2258	13.9859	13.4654	12.801	11.1863
4	13.4347	12.7551	12.136	13.7038	11.804	12.6587	12.025
5	11.8921	13.9686	15.6416	14.4545	13.4572	13.7794	11.6431
6	10.9375	12.4408	13.0821	13.7689	11.8436	12.8206	11.3555
7	12.3317	12.4373	13.2243	14.3465	14.062	12.7247	12.8887
8	13.4322	14.7651	15.5559	10.8308	12.329	13.1575	12.1511
9	12.1216	13.568	15.591	14.3564	14.6905	13.548	13.5638
10	12.0801	15.4708	14.2696	13.2546	14.1349	14.3359	13.169
11	9.8874	9.925	12.0163	10.8124	10.6228	11.0256	10.7284
12	10.8083	13.5242	15.3147	13.2405	12.7331	13.3826	13.0908
13	12.6724	12.2323	13.9777	14.6588	12.7399	12.9755	10.91
14	12.1943	11.1814	13.6929	12.9383	14.5901	12.6385	13.7629
15	10.4331	13.3297	13.8783	13.7098	12.7819	11.5674	12.6877
16	12.7503	12.3125	13.4821	14.3683	12.0635	13.288	14.2465
17	11.3529	13.3905	13.1808	14.0221	13.4306	12.8425	12.334
18	11.5518	12.7886	13.7633	14.2983	12.915	11.9758	11.4723
19	11.8566	13.4822	13.6187	13.941	13.267	13.164	12.6054
20	11.2685	12.8595	13.0978	13.6608	13.6319	12.9658	12.7212

Raw Data's of Body Center of Mass (COM) Linear Velocity

Subject	COM1	COM2	COM3	COM4	COM5	COM6	COM7
1	1.784	2.108	1.661	2.057	1.336	1.539	0.598
2	2.195	1.847	1.461	1.405	0.932	0.68	0.469
3	2.876	2.015	2.254	2.105	1.537	1.17	0.511
4	1.93	1.972	2.226	2.268	1.721	1.277	0.672
5	2.512	2.739	2.943	2.49	1.931	1.652	0.879
6	1.907	1.825	1.333	1.507	0.936	0.536	0.16
7	1.689	1.475	1.518	1.931	1.475	1.249	0.85
8	1.877	2.141	1.958	1.369	1.141	0.951	0.516
9	2.442	2.03	2.447	2.244	1.741	1.285	0.573
10	2.214	2.713	2.447	2.247	1.891	1.126	0.352
11	0.769	1.174	1.28	1.036	0.904	0.594	0.439
12	1.729	1.975	2	1.777	1.499	1.127	0.568
13	2.218	1.624	1.773	1.768	1.425	1.373	0.953
14	2.004	1.705	1.94	1.469	1.429	1.316	0.678
15	1.75	1.915	1.912	1.828	1.509	1.211	0.619
16	2.087	1.68	1.611	1.481	1.416	1.305	0.904
17	1.795	1.994	2.259	1.716	1.472	1.155	0.776
18	1.981	1.78	1.731	1.669	1.396	1.326	0.941
19	1.832	1.94	1.894	1.845	1.377	1.057	0.658
20	1.937	1.872	1.723	1.689	1.478	1.228	0.976

Appendix C (continued)

Raw Data's of Linear Velocity of Ball (LVB)

Subject	LVB1	LVB2	LVB3	LVB4	LVB5	LVB6	LVB7
1	15.8551	16.4845	20.1973	16.1903	17.0342	17.5031	16.9287
2	14.7024	14.8768	15.7875	15.7166	16.9228	15.8793	15.5986
3	14.5915	14.3931	15.1543	16.7183	15.9249	15.1891	16.1001
4	15.4615	18.2719	18.8398	18.4203	17.6504	15.2485	14.7112
5	13.8711	14.5838	15.6028	17.6441	15.7063	16.5085	15.2013
6	15.6013	15.6281	17.8371	17.6981	17.1395	17.0296	14.7468
7	14.8643	17.0762	18.5934	20.7187	18.2706	17.5901	13.6837
8	15.4349	17.2824	18.9951	20.2621	18.3313	16.0047	15.9616
9	15.6317	15.7978	18.5942	17.8723	16.6834	16.9392	15.9066
10	13.6637	14.414	14.7042	18.0077	14.8638	14.9529	14.6824
11	12.2896	15.3281	15.9795	18.2412	15.4154	14.6957	14.6387
12	14.4826	17.6258	18.2384	20.0844	18.3863	17.8118	17.1232
13	14.1825	16.7272	16.4569	18.3634	18.6247	17.7954	15.99
14	15.1357	16.3621	16.9885	17.4938	17.7151	16.1465	15.7719
15	15.5862	17.1693	18.1928	20.4632	17.0694	16.5419	16.9885
16	14.4925	16.3276	18.6676	20.2218	18.0154	16.7353	15.9766
17	16.6384	18.5845	19.3005	20.121	19.1225	18.9839	17.7443
18	16.037	18.0921	18.9981	19.1035	18.7589	17.3727	15.4997
19	14.516	16.5306	17.4431	19.8564	17.6513	16.5461	15.8928
20	15.4187	17.931	18.9808	19.0671	17.9933	17.4829	16.3358

Raw Data's of Angular Velocity of Hip Joint (HAV)

Subject	HAV1	HAV2	HAV3	HAV4	HAV5	HAV6	HAV7
1	366.3	173.83	314.12	255.67	386.05	416.14	364.26
2	91.28	85.8	189.27	7.25	44.96	201.52	214.55
3	131.88	84.24	227.68	192.36	98.22	190	124.42
4	253.69	13.54	237.56	232.27	16.29	465.05	309.27
5	405.87	192.65	0.18	242.86	58.01	228.72	248.27
6	59.24	103.9	257.8	326.77	204.72	332.24	2.47
7	197.83	158.27	171.37	202.26	395.61	341.98	155.73
8	189.91	160.73	249.77	355.9	42.09	68.9	63.88
9	248.74	201.23	203.02	294.61	33.92	130.41	30.82
10	265.39	208.34	230.87	287.74	411.72	293.86	433.12
11	38.91	223.13	79.96	88.92	53.86	70.6	70.67
12	116.54	102.14	89.95	272.98	65.7	37.61	282.83
13	33.27	102.77	57.76	7.63	132.64	193.4	335.92
14	135.73	42.82	40.73	119.72	268.54	60.64	69.81
15	137.12	73.66	162.44	240.21	2.16	204.39	8.07
16	12.72	138.81	96.16	178.95	95.03	122.7	245.99
17	190.95	124.34	122.33	268.54	53.3	147.1	185.23
18	22.02	266.64	137.71	162.12	203.24	39.64	73.35
19	135.74	105.39	110.4	112.23	125.93	213.07	83.53
20	45.97	278.25	160.59	187.93	158.47	14.26	102.57

Appendix C (continued)

Raw Data's of the Angular Velocity of Knee Joint (KAV)

Subject	KAV1	KAV2	KAV3	KAV4	KAV5	KAV6	KAV7
1	715.01	793.49	881.47	984.32	713.14	728.84	539.92
2	797.05	674.47	531.9	748.62	666.97	507.8	306.97
3	792.29	1178.15	924.87	1037.31	666.1	658.71	451
4	641.33	1058.35	807.43	361.88	539.69	281.05	428.82
5	768.55	749.33	802.89	659.27	484.59	445.81	313.86
6	880.23	853.82	733.74	766.7	673.71	807.06	884.54
7	826.24	834.93	844.66	778.66	835.16	599.04	828.08
8	965.65	880.83	917.07	439.06	716.94	760.07	713.14
9	776.39	706.73	638.24	883.74	704.57	360.98	374.81
10	787.88	891.27	1002.72	855.69	888.29	887.61	638.2
11	968.56	0.73	877.79	744.53	946.53	601.08	531.27
12	574.31	740.06	763.79	880.87	970.47	606.37	616.38
13	771.5	688.89	748.45	994.4	821.42	787.69	842.23
14	868.75	574.56	733.11	765.01	1093.5	790.57	645.73
15	587.57	787.1	713.45	865.04	825.94	778.18	714.06
16	1068.21	672.18	796.79	629.23	844.75	700.42	780.83
17	592.79	883.91	648.53	628.06	813.27	727.31	743.96
18	1048.62	800.62	721.84	714.64	810.35	679.98	769.63
19	928.43	822.94	938.38	824.98	778.22	645.36	624.15
20	1024.27	805.24	649.6	740.91	759.67	652.99	751.82

Raw Data's of Angular velocity of Ankle Joint (AAV)

Subject	AAV1	AAV2	AAV3	AAV4	AAV5	AAV6	AAV7
1	524.75	451.48	1049.17	491.38	992.61	948.46	602.56
2	138.9	296.77	458.78	69.69	490.32	567.02	493.37
3	189.74	657.95	164.49	119.86	279.33	545.26	719.7
4	372.34	801.47	218.86	780.06	566.95	604.11	328.76
5	320.96	151.71	528.58	461.69	190.45	397.62	528.39
6	347.22	31.87	473.87	68	75.38	641.56	5.27
7	457.6	649.49	585.78	842.94	5.97	787.11	403.59
8	116.63	371.68	391.39	376.28	22	279.86	403.79
9	820.81	161.95	644.43	770.12	446.57	633.02	425.61
10	214.78	162.43	108.02	656.31	475.35	432.86	378.36
11	31.04	1192.51	343.77	229.67	319.49	212.15	353.85
12	381.79	16.23	42.04	424.65	141.06	424.47	974.23
13	78.45	67.66	103.81	204.11	178.04	273.67	329.68
14	514.4	104.55	40.66	164.17	251.9	353.19	424.85
15	230.91	92.39	395.84	19.47	410.98	323.53	788.17
16	160.48	142.83	48.97	186.56	374.51	27.3	835.01
17	480.1	566.99	127.25	523.03	542.58	711.26	782.89
18	448.67	351.45	521.59	587.15	612.02	586.58	583.61
19	968.05	618.05	477.78	94.55	777	747.39	549.12
20	206.66	520.95	349.54	710.17	872.07	833.36	748.82

Appendix D

Table 1 Result of the Bonferroni Post -Hoc Test for Significance Among the means of the Approach Angles on DCB

Mean	AA	0°	90°	15°	75°	30°	60°	45°
28.92	0°							
30.65	90°	*						
32.89	15°	*	*					
33.68	75°	*	*					
35.67	30°	*	*	*	*			
36.42	60°	*	*	*	*			
39.01	45°	*	*	*	*	*	*	

* Indicates significant differences at 0.05 level of confidence
Mean difference value needed for significance at .05 level of confidence was 1.15

Table 2 Result of the Bonferroni Post -Hoc Test for Significance Among the means of the Approach Angles on Accuracy of the Kick

Mean	AA	45°	60°	30°	75°	15°	90°	0°
0.92	45°							
1.42	60°							
1.56	30°	*						
2.36	75°	*	*	*				
2.96	15°	*	*	*	*			
3.21	90°	*	*	*	*			
4.11	0°	*	*	*	*	*	*	

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.373

Appendix D (continued)

Table 3 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on LVH at BC

Mean	AA	90°	75°	60°	45°	30°	15°	0°
0.34	90°							
0.36	75°							
0.61	60°	*						
1.07	45°	*	*	*				
1.28	30°	*	*	*				
1.39	15°	*	*	*	*			
1.56	0°	*	*	*	*	*		

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.188

Table 4 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on LVK at BC

Mean	AA	90°	0°	75°	60°	15°	45°	30°
2.46	90°							
2.87	0°	*						
2.91	75°	*						
2.99	60°	*						
3.17	15°	*						
3.20	45°	*						
3.27	30°	*	*					

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.29

Appendix D (continued)

Table 5 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on LVA at BC

Mean	AA	90°	0°	15°	60°	45°	75°	30°
9.94	90°							
10.19	0°							
10.29	15°							
10.39	60°							
10.47	45°							
10.48	75°							
10.73	30°	*						

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.54

Table 6 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on LVT at BC

Mean	**AA**	0°	90°	60°	15°	75°	45°	30°
11.90	0°							
12.45	90°							
13.01	60°	*						
13.02	15°	*						
13.03	75°	*						
13.62	45°	*	*					
13.74	30°	*	*					

*Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.59

Appendix D (continued)

Table 7 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on COM at BC

Mean	AA	90°	75°	60°	45°	30°	15°	0°
0.65	90°							
1.16	75°	*						
1.43	60°	*	*					
1.80	45°	*	*	*				
1.92	30°	*	*	*				
1.93	15°	*	*	*				
1.98	0°	*	*	*				

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.15

Table 8 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on LVB at BTO

Mean	AA	0°	90°	15°	75°	60°	30°	45°
14.92	0°							
15.77	90°	*						
16.47	15°	*						
16.65	75°	*	*					
17.36	60°	*	*	*				
17.68	30°	*	*	*	*			
18.61	45°	*	*	*	*	*	*	

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 0.57

Appendix D (continued)

Table 9 Result of the Bonferroni Post Hoc Test for Significance Among the means of the Approach Angles on KAV at BC

Mean	AA	90°	75°	45°	15°	60°	30°	0°
624.97	90°							
650.35	75°							
765.15	45°							
769.88	15°	*						
777.66	60°	*						
783.84	30°	*						
819.18	0°	*	*					

* Indicates significant differences at 0.05 level of confidence.
Mean difference value needed for significance at .05 level of confidence was 103.04