BIOMECHANICAL PARAMETERS OF PUNT KICKING

by

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Chapter 1

INTRODUCTION

Punting may well be the most superfluous of the kicking skills in American football. A punt has no scoring potential even though it may be used for a free kick, from scrimmage or at almost anytime a player has the ball in his hands (57). Once the ball is punted the opposing team is entitled to possession. The punt kick's salvation remains in a final offensive move, usually after three downs, in clearing the ball away from a potentially dangerous position in a team's own end zone area.

Allen (6) stated that the kicking game accounts for over 60 percent of the lost yardage and 25 percent of the scoring in a football game, and that in the 1968 NFL season 62 percent of all yardage made was a result of all phases of the kicking game. Despite similar acclaim of how important kicking is (5, 28, 35, 43, 52, 58), it appears that the most successful teams do not have to punt the ball as much as the least successful.

Berger (9) used the 1972 results of 139 games played by 41 San Diego County High School teams to investigate the relationship of the kicking game to selected performance variables. He found that the actual net advance of the average kick-off was 22.8 meters (25 yards) compared with 25.6 meters (28 yards) for the punt. Berger (9) concluded that the kicking game performance of a team is related to successful performance in a game, but the season average kicking game performance was not significantly related to successful performance for a season. Based on linear regression equations, Berger estimated that the combined effect of all kicking aspects in a football game was 12.6 points a game.

With possession of the ball and field position so important in a game, it is desirable that the punt kick generally combine both maximum height and distance. The distance aspect is to take some of the pressure off the in-coming defense by having them start in their opponent's half. The height aspect is to enable the offense to cover the ball where and when it lands (or is caught) and so prevent a run-back which can destroy the very essence of the distance attained in the kick (28). Situations can arise, though, where a long, low kick out of bounds may be better than a high one.

The role of the punter in a football squad is usually that of a specialist. Most teams have more than one kicker. In college ranks the number one kicker usually punts and placekicks (for extra point, kick-off and field goal). In the professional game these skills may have separate personnel. It is not uncommon in professional ranks to have a kicker that can execute a throwing option.

STATEMENT OF THE PROBLEM

With limited opportunities to punt kick, and with a specific specialized function, the punt kicker on an American football team should be the most skilled kicker available. Highly skilled athletes usually perform their skills with an economy of movement, great precision and a minimum of time. High skill level suggests that a kicker's performance is anatomically and mechanically sound. What is not fully understood or documented at this time are the biomechanical parameters in which the expert punt kicker excels.

The problems involved in this investigation were twofold: (a) to establish a list of biomechanical parameters of punt kicking; and (b) to isolate from these parameters specific factors associated with superior performance.

PURPOSE OF THE STUDY

The purpose of this study was to establish, by cinematographical analysis, biomechanical parameters of punt kicking an American football. By determining and investigating the relationship of a number of variables associated with the performance of an expert kicker over a number of trials, some guidelines were established as to what are the most important parameters in successful punt kicking.

NEED FOR THE STUDY

Very little biomechanical data exists for punt kicking (2, 18, 45, 52, 59). Most of the literature pertaining to football merely contains sections on how to kick (8, 10, 13, 25, 27, 31, 35, 44, 55, 56, 57, 64) with little or no reference made to any research. Opinions, personal experience and handed-down success stories well summarize the abundance of how-to-kick articles in journals and chapters in books.

To optimize the teaching of punt kicking skills, teachers and coaches need to better understand the mechanics of kicking and the importance of the foot's placement on the ball (45). It is impossible to see exactly what occurs in a skill that involves ball contact for 0.015 of a second (47). Recent advances in high speed cinematography have made possible the analysis of rapid movement skills (7, 14, 15, 30, 33, 41).

DELIMITATIONS OF THE STUDY

From a total of thirteen kicks filmed, trials 1 to 12 inclusive were analyzed. The thirteenth kick was omitted due to time restrictions associated with the use of the Vanguard Motion Analyzer. The biomechanical parameters established were representative of only the analyzed kicks, which ranged in distance from 43.9 meters (48 yards) to 61.3 meters (67 yards). Fifty-one frames per trial were analyzed.

Filming was outdoors at the KSU Football Stadium under a non-competitive situation. The subject was instructed to kick for maximum distance. The measured distance was from contact to the point of landing. The roll of the ball was not included. Comments were recorded as to whether the kick went left, right or straight (see Appendix D).

LIMITATIONS OF THE STUDY

It is recognized that the results obtained in this study may have been influenced by one or more of the following limitations.

1. One expert performer was the subject. He was the best available for the study. With a subject N of 1, little inference can be made to the population of kickers (22, 23, 24).

2. The subject was only briefly clad to assist the subsequent joint center location from the film.

3. The lack of a defensive rush and the regular expert center to snap the ball to the kicker rendered the filming conditions quite dissimilar to those found in the game situation.

4. Uni-axial photography necessitated some estimation of the opposite joint center coordinates. Some resolution error existed in the instrumentation involved in the analysis. As well, human perspective

error is recognized (62).

5. The choice of frame rate for the camera's recording of the kicking action was an arbitrary one. The rate of 500 frames per second (fps) ultimately was effectively reduced by selecting every fourth frame for analysis. This sampling rate was assumed to contain most of the significant frequency components of the signal (14).

DEFINITION OF TERMS

<u>Ball Angle</u>

Relationship of the ball to the horizontal, calculated from the ball end point coordinates.

<u>Ball Release</u>

From hands: first frame in which the right hand is removed and the ball commences free fall.

From foot: first frame in which ball obviously is clear of the foot.

<u>Center of Gravity</u>

Center of mass of the body.

<u>Cinematography</u>

Use of film to record human physical performance.

<u>Criterion Variable</u>

Distance of the kick was the criterion variable measure used to correlate all other variables in this study.

<u>Heel Plant</u>

Refers to the first frame in which the support foot makes contact with the ground in the final approach step.

Parameters

Measurable variables associated specifically with punt kicking.

Segmental Analysis

A method of calculating the center of gravity of an individual using data according to Dempster (21).

Wildcat Computer Program

A Fortran computer program written at Kansas State University specifically for biomechanical analyses.

Chapter 2

REVIEW OF LITERATURE

Very little biomechanical data deals exclusively with punt kicking an American football. There is a plethora of popular literature that purports to give the ultimate in advice and coaching tips to the aspiring kicker and to remedy faults that may be apparent in the experienced kicker. This chapter is divided into two parts. The first part deals with kicking in general. The second part deals exclusively with variables associated with punt kicking. The first part reviews selected literature and all the known available punt kicking studies. The review commences with the writing of Leroy Mills (43), in 1936, and follows a chronological progression.

KICKING

The art of kicking has undergone many changes in the game of American football (28). Mills (43) was an active kicking coach when the now defunct drop kick was widely used. His teaching formed the basis of most of the accepted kicking practices. Mill's success came apparently in spite of his belief that the distance acquired in the kick came predominantly from the follow through, rather than what he termed sudden contact or smash against the ball. He did require his charges to kick accurately. The coffin-corner kick was used often then. This form of accurate punting is currently undergoing a small revival (16).

Stewart (54), in 1948, presented the most comprehensive

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bibliography of football references from 1900 up to that time. Reference was made to some fifty-eight articles dealing exclusively with the punt kick. As well as rule changes, the shape and size of the ball has changed since then.

Miller (42) and Smith (52) have provided a very comprehensive history of kicking in American football. Summerall (58) devoted a large part of his book to the history of the kick in most codes of football. Specifically he gave attention to great American kickers, such as Thorpe, Groza and Gogolak, and lamented the decline in the standard of punt kicking. In 1940, Sammy Baugh was the leading punter, averaging 47 meters (51.4 yards), while in 1960 the top ten punters in the NFL averaged 37-39 meters (40.7-42.9 yards) (58).

The first cinematographical analysis of punt kicking was by Smith (52) in 1949. He investigated punt kicking with three kickers: an expert, an average and a novice. He found marked differences in such factors as height of release of the ball, height of the ball at impact, time taken for the kick and resultant ball velocity. The expert kicker dropped the ball a smaller distance to the foot (hence had greater control and less chance of error) and took less time to complete the kick. In this study the subjects were filmed at 48 frames per second. The relative findings are summarized in Table 1.

Table 1

Skill Factor Differences in Punting (52)

	Expert		Average		Novice	
Distance ball dropped, mm	163	(6.4")	457	(18")	762	(30")
Velocity of ball at release*, m/s	28	(92')	26.5	(87')	22.6	(74')
Distance kicked, meters	55.8	(61 yds)	52.1	(47 yds)	42	(46 yds)
Launch angle*, degrees**	47.5		31.5		32	
Time per kick, seconds	1.38		1.55		1.70	

*release from foot

**degrees from the horizontal

Since 1949 a great deal more attention was given place kicking (6, 11, 12, 20, 26, 40, 49, 53). Marshall (40) used a mechanical kicking machine to determine the effect of five factors upon place kicking for distance. These factors were: (a) the point of impact of the toe on the ball; (b) the type of football used; (c) the use of a detachable rubber kicking toe; (d) the placement of the laces of the ball; (e) the inflation of the ball.

Marshall (40) found no difference in the following factors: types of footballs used (leather or rubber), placement of the laces of the ball while on the tee, usage of the detachable rubber toe piece or changing the pressure in the ball from 62,000 Nm^{-2} to 103,00 Nm^{-2} (9-15 lbs per square inch). He established that the optimum point of contact was 140 mm (5½") up the seam when the ball was tilted 15 degrees toward the kicker and the tee set 380 mm (15") in front of the point directly below the ankle.

Marshall (40) concluded that a medium high, slowly revolving end-over-end kick resulted in optimum height and distance. Extra height could be gained by tilting the ball greater than 15 degrees toward the kicker, or by kicking it lower down the seam.

Many authors have reported little difference in the mechanical principles of place kicking and punt kicking (13, 17, 29, 34, 40, 45, 51, 53, 61). Others have stated that kicking is merely an extension of running (29, 45, 47). Kicking differs from walking and running in that the primary force is generated in the rotating limb rather than the support limb. The speed of the swinging limb also is greater in the kick than in the run (63).

The introduction of soccer style place kicking gave impetus to research on football kicking in the 1960's and early 1970's (11, 12, 20, 26, 53). Bona (12), in 1963, found no significant difference between the instep versus the toe kick for either distance or accuracy, nor between the distances attained using either a rubber or a leather ball. Stalwick (53), in 1967, while analyzing the kick-off stated that the principles and mechanics of punting apply in similar degree to all forms of kicking. In the same year, Blaettler (11) presented a specific mechanical analysis of the place kick. Both authors suggested three main sources of force in kicking: the linear movement of the kicker, the rotary action of the kicking leg about the hip joint, and the action of rapid extension of the lower leg (11, 53).

Davies (20), in 1969, and Eldridge (26), in 1971, both investigated different methods of place kicking. Davies (20) compared soccer style place kicking and the American toe kick, while Eldridge (26) compared the rugby toe kick with the American style. Eldridge (26) used both experienced and non-experienced subjects (N = 53) and found no significant difference between the two styles in accuracy or kick-off distance. Davies (20) used two subjects and reported favorably on the effectiveness of the soccer style place kick. Marciniak (39) was an advocate of this style of kick for the extra point.

Plagenhoef (45), though, has shown that there is very little difference in the resultant ball velocity between the straight approach kick with the toe or the angled medial instep (soccer) kick. He indicated that the important factor is the placement of the foot on the ball. The nature of the contact area between the foot and the ball is critical in all kicking.

In 1960, in an experimental comparison of end-over-end and spiral punting, Miller (42) gave evidence of this contact area. Figures 1 and 2, traced from photographs, illustrate the two types of contact.

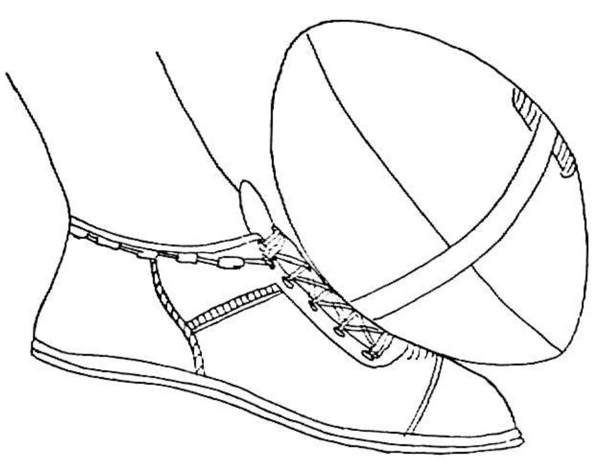

Figure 1

Spiral Contact

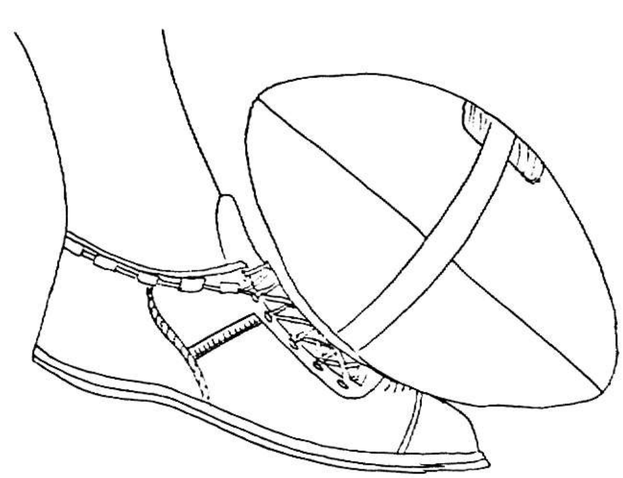

Figure 2

End-Over-End Contact

It appeared from the photographs that the spiral kick was produced by having the ball at an angle across the foot at contact. It further appeared that for both types of punt the ball was contacted on the instep. The ten kickers in Miller's study (42) were experienced spiral punters and were coached over a two week period with the end-over-end punt.

The 1974 work of Alexander and Holt (2) contradicted the ball contact positions suggested by Miller (42). They compared two experienced (right foot) Canadian kickers. By analyzing their best kicks (54.8-61.3 meters; 60-67 yards) and average kicks (36.6-41.1 meters; 40-45 yards) they indicated that the critical factor in punting was maximizing the transfer of force from the foot to the ball. This disagreed with the generally accepted theory that the speed of the foot is the critical factor.

Using high-speed (150 fps) film and computer reduction of the data, Alexander and Holt (2) showed that the best contact area was across the anterior of the ankle. The contact centered primarily on the distal end of the tibia and fibula, the talus naviculus, cuboid and cuniform bones. With the foot plantar flexed, this bony surface provided a far superior contact surface than the usually recommended instep. Kicking with the instep involved contact with the metatarsals; Alexander and Holt (2) said contact here usually will cause some decrease in force transference (see Figures 3 and 4).

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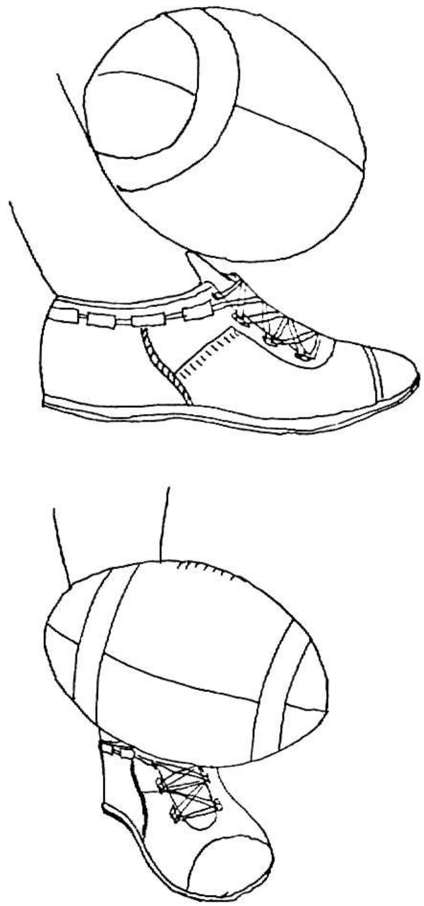


Figure 3

'Good' Contact

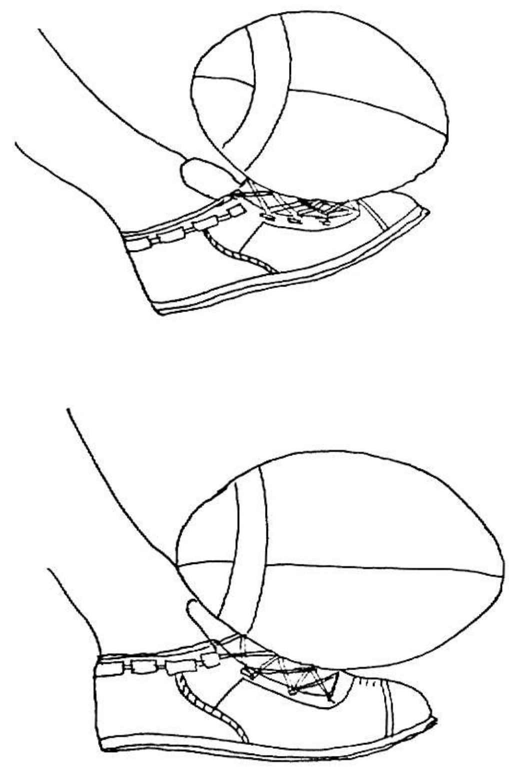


Figure 4

'Poor' Contact

Cunningham (18), in 1976, analyzed three types of punt kicking using two kickers from the Texas A & M varsity team. He found that a Type I punt, one whose long axis followed its trajectory of flight and landed on its front edge, was superior in distance, efficiency and initial velocity to a Type II punt, one that traveled at an angle to its trajectory and landed with the long axis of the football parallel to the ground, and a Type III punt, one that traveled at a marked angle to its trajectory and landed on its rear tip.

Cunningham (18) listed several characteristics of the superior type I punt (see Table 2).

Table 2

Characteristics of a Type I Punt (18)

Distance, meters	55	(60 yards)
Initial velocity, m/s	33.5	(110 ft/s)
Launch angle, degrees	50	
Contact height, mm	530	(21")
Follow through angle of the kicking leg in relation to the midline of the body, degrees	7	

In 1975 and 1976 reported studies, Macmillan (37, 38) used high-speed cinematography to gather data from four subjects to establish the kinesiological determinants of the path of the foot during the football kick in Australian football. Body velocity, defined as the linear velocity of the iliac crest at the frame on which maximum foot velocity occurred, was not related to kicking foot velocity. As body velocity increased and the ball traveled further, the greater ball travel was not due to any increase in foot velocity at impact, but was due to the higher launch angle given to the ball. This launch angle is defined as the angle of the resultant displacement path of the ball with the horizontal. Opinion varies slightly as to the optimum launch angle. These data are summarized in Table 3.

Table 3

Optimum Launch Angles

Researcher	Year	Angle, Degrees
Smith (52)	1948	47.5
Alexander & Holt (2)	1974	40-45
Watson (59)	1974	51
Macmillan (37)	1975	40
Cunningham (18, 19)	1976	50

In the most authoritative study reviewed, Alexander and Holt (3), in 1976, listed several factors they claimed were mechanically sound and should result in effective punting. These factors were:

1. The ball should be released in a horizontal plane.

2. The ball should be dropped so that it makes an angle of approximately 25 degrees across the foot, thus preventing premature contact with the ends of the football.

3. In transferring the ball from the hands to the foot, the ball must describe an arc (due to the force of gravity and the horizontal velocity of the ball).

4. The anterior distal aspect of the ankle is the optimum contact point.

5. This contact should be through the center of gravity of the ball.

6. The ball must roll down and off the foot to create a spiral.

In this study (3), the authors filmed three kickers at 300 fps. They found supporting evidence for their earlier finding (2) that the critical aspect in punting is the effective transfer of force to the ball. They found that with each subject the foot velocity for the average punt was greater than the foot velocity for the superior punt.

A review of the literature on kicking has established some common ground in that there exists a basic pattern of movement common to most types of kicks. This similarity was recognized by several authors (17, 29, 45, 47, 61). The pattern is essentially as follows:

1. Once the support foot has been placed, rotation of the pelvis at the hip joint of the support leg occurs. The magnitude of this rotation is related directly to the length of the last approach step and the angle of this approach (39, 45).

2. The thigh of the kicking leg is brought forward by hip flexion. Pelvic rotation assists this movement.

3. Knee flexion reduces the angle between the thigh and the lower leg as the thigh moves forward.

4. The thigh decelerates and almost stops flexing at the hip joint as knee extension begins and rapidly accelerates.

5. After ball contact the thigh flexion continues with the knee in the fully extended position. At the time of contact, knee extension is the major joint action contributing to foot velocity (11, 13, 17, 47).

SPECIFIC PUNT KICKING VARIABLES

The action of punt kicking can be broken down into five distinct phases. These are the approach, the support foot plant, ball release, ball contact and follow through. A further breakdown of these phases is presented in Figure 5.

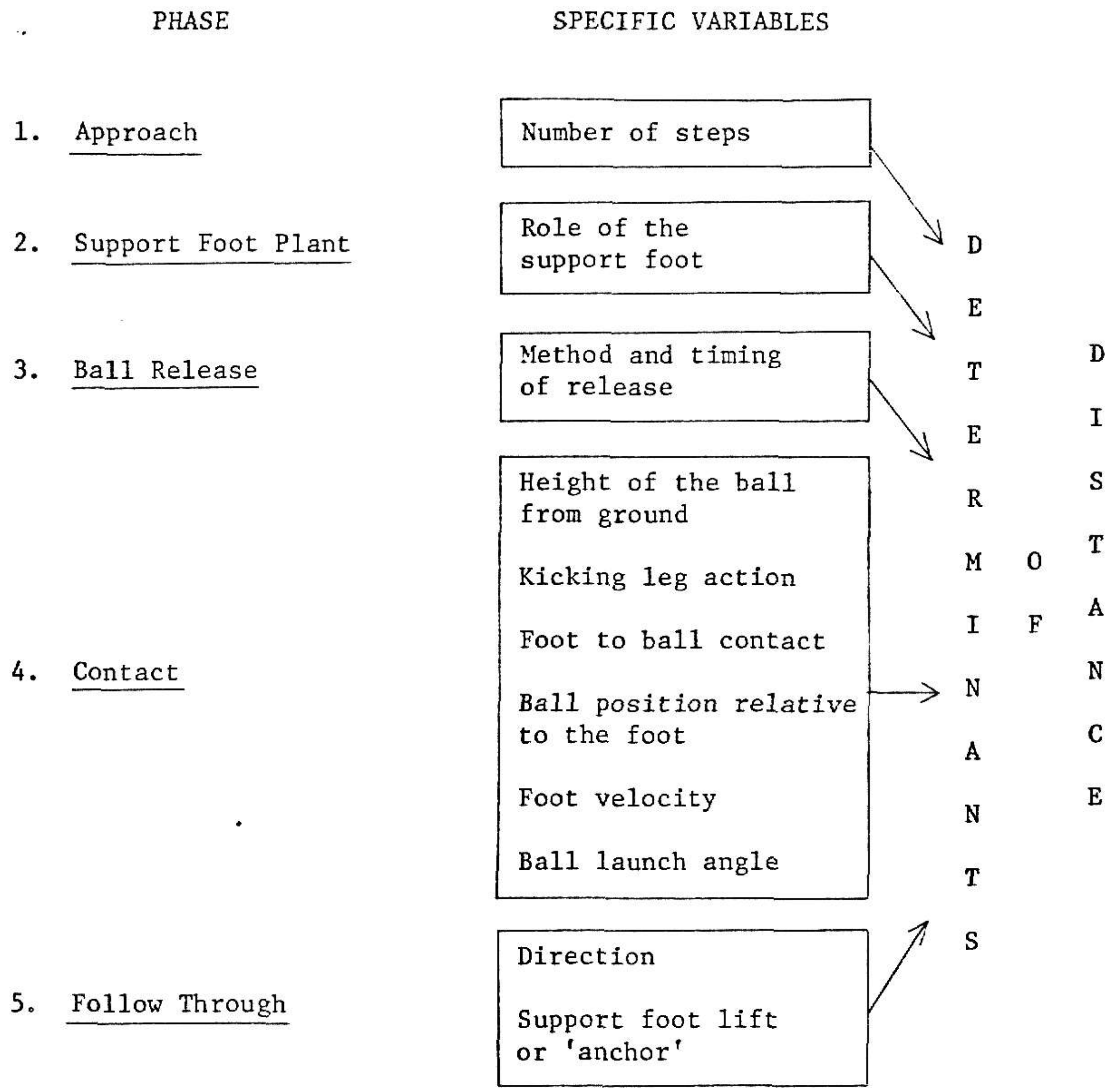


Figure 5

Punt Kick Analysis

The number of steps taken in the approach to a punt kick appears to be dictated by a personal preference, rather than any 'magic' number. This personal preference may be shaped by a coach and/or the team's ability to provide adequate blocking. Some optimum distance for a center snap may also be a crucial factor. Various opinions from the literature are presented in Table 4.

Table 4

Number of Approach Steps

Author	Year	Number
Fuoss (28)	1959	1.5
Miller (41)	1960	2
Murray & Falcone (44)	1970	1.75
Allen (4)	1970	3
Watson (59)	1974	4
Albright & Carlson (1)	1976	3
Belichick (8)	1976	1.5-2 max
Hager (31)	1977	2 or 3

There is a great deal of conflicting opinion in the popular literature as regards the role of the support foot in punt kicking. The support limb's role has generally been avoided in the few serious studies reported (2, 3, 18, 19, 37, 42, 52). The implications of the apparent confusion and lack of definite knowledge are presented in Table 5.

Table 5

Role of the Support Foot

Author	Year	Implication
Mills (43)	1936	Used only for balance and aim as kickers foot had a natural tendency to align with it. Foot must be flat and solid on the ground.
White (60)	1954	Determines direction of flight of the ball
Fuoss (28)	1959	Must remain on the ground for two reasons: (a) for greater consistency and accuracy, (b) to prevent toes of kicking foot turning up
Young (64)	1959	A pointer foot
Summerall (58)	1968	Foot should stay in contact with the ground
Kahler (35)	1969	In natural position and in line with the kick
Storey (57)	1974	Must be kept on the ground during follow through to prevent loss of power
Belichick (8)	1976	At impact, the support foot should be flat on the ground and should retain contact with the ground thereafter.
Hager (31)	1977	Support leg remains on the ground during kicking lower leg extension; follow through causes a total body lift.

There is some agreement in the above that the support foot should remain on the ground, but the authors, with the exception of Belichick (8) and Storey (57), do not indicate exactly how long the support foot should remain on the ground. It is obvious that a kicker has to have some support and some method of applying force against his environment. The support foot role during the follow through remains unclear (32).

There was a general consensus of opinion that the ball drop is an important factor in punt kicking (2, 3, 8, 31, 35, 44, 46, 64). Alexander and Holt (3) claimed that the manner the ball is initially released will determine the following:

1. the angle at which the ball will land across the foot.

2. the angle of the ball to the ground; that is, the angle relative to the horizontal and whether the ball is elevated or depressed at either end.

3. the relationship of the center of gravity of the ball with the mid-line of the body of the kicker.

Other opinion on ball release is presented in Table 6.

Table 6

Ball Release (from hands)

Author	Year	Suggestion
Pudlowski (46)	1959	Left hand is withdrawn first; right hand remains under the ball for as long as possible
Young (64)	1959	Ball should be dropped flat, so that its long axis is parallel to the ground or turned slightly towards the inside of the foot. Ball is dropped from approximately knee height
Kahler (35)	1969	Laces on top, ball turned in at front and somewhat depressed. Ball drops in line with the outside of the kicking leg
Murray & Falcone (44)	1970	Ball pointed inward slightly. Both hands are used in the drop and pulled sideward away from the ball
Alexander & Holt (2)	1974	Allow the ball to fall with gravity
Alexander & Holt (3)	1976	For superior punts: ball released close to horizontal, close to the mid-line of the kicker and at 27 degrees to this mid-line as opposed to 21 degrees in an average punt
Belichick (8)	1976	Ball is positioned at precise angle wanted for the drop. Left hand placed forward and on the bottom side of the ball; right hand on the back part of the ball, either on top or completely underneath
Hager (31)	1977	Right hand cups ball underneath and toward rear; left hand at front and underneath ball, slightly to left side but with laces up. Ball is dropped flat with no twists or turns

From Table 6, it appeared that the ball drop was a passive action on the part of the kicker. Once the ball was established in the hands there was no suggestion that the kicker do anything more than just let the ball go, with the hope that it would be in the same position as when released. Ideally the ball should be placed directly onto the foot but anatomically this would limit the kickers ability to swing the kicking leg through.

In the contact phase of the punt kick a great deal more information was available. There was reasonable agreement in the literature that the ball height from the ground at contact should be approximately 380 mm (15"). This figure would be influenced by the height of the kicker and the particular game conditions. For instance, if height and good coverage was required then the ball may be struck at a higher point than that when a long low out of bounds kick was required. The information on ball height from the ground is summarized in Table 7.

Table 7

Ball Height (from ground) at Contact

Author	Year	Implication
Smith (52)	1949	Expert 670 mm (2.2') Average 335 mm (1.1') Novice 488 mm (1.6')
White (60)	1954	Low when against the wind; greater than 610 mm (2') if height and coverage is required
Fuoss (28)	1959	For height: above waist height; for distance: slightly below knee height
Kahler (35)	1969	Hip height
Allen (5)	1970	305-410 mm (1'-1.5')
Bunn (13)	1972	380 mm (1.25')
Hay (32)	1973	From 230-760 mm (.75'-2.5') according to conditions and requirements
Storey (57)	1974	410 mm (1.5')
Cunningham (18)	1976	535 mm (1.75')

It generally is implied that when kicking into a head wind the ball should be contacted closer to the ground. This presumably keeps wind resistance to a minimum and so guarantees a respectable distance. Little is known about the aerodynamics of a football in flight. Mills (43) is the only author to refer to the football (as it was in the 1930's) as a prolate spheroid. More research is needed on this aspect.

Cunningham (18) claimed that wind resistance factors reduced the possible distance of a punt kick by as much as 50 percent. Kicking leg comments relative to the punt kick are reviewed in Table 8.

Table 8

Kicking Leg at Contact

Author	Year	Implication
Glassow & Mortimer (29)	1968	Close to full extension
Kahler (35)	1969	Extended forcibly and locked
Allen (5)	1970	Straight (p175): but slight bend at knee (on following pages)
Wickstrom (61)	1970	Leg almost straight
Albright & Carlson (1)	1976	178 degree angle at knee
Cooper & Glassow (17)	1976	Almost full extension
Hager (31)	1977	Straight leg, ankle locked and toes pointed

Anatomically the kicking leg at ball contact was reported as being close to full extension. Reference was made to the so called leg 'snap' in punting. This term has referred to the rapid extension of the lower leg at a time when the thigh has slowed (5, 13). Extension at the knee is the major joint action contributing to foot velocity in the kick (11, 13, 17, 47).

In such a fast action as the punt kick, in which the ball is in contact with the foot for 0.015 seconds (29), it would seem that this impact aspect is extremely important. Ryder and Bennett (50) confirm this opinion. They state that if a force is applied to a deformable body (such as a football), the effect generally will be dependent on the point of application as well as on the magnitude and direction.

There was considerable support in the literature for the instep as being the optimum area of contact. The more recent study by Alexander and Holt (2) has cast considerable doubt on this. The various opinions as to the optimum area of contact are presented in Table 9.

Table 9

Foot - Ball Contact

Author	Year	Implication
Allen (4)	1950	Across the instep
White (60)	1954	Instep (or arch of the foot)
Fuoss (28)	1959	'Thick' part of foot
Pudlowski (46)	1959	Instep
Young (64)	1959	Instep
Scott (51)	1963	Instep
Summerall (58)	1968	Outside of Instep
Kahler (35)	1969	Well up the foot
Murray & Falcone (44)	1970	Toes pointed down
Bunn (13)	1972	Hard dorsal surface and to the outside of the foot
Alexander & Holt (2)	1974	Anterior portion of the ankle; contact time approximately 0.014 seconds
Macmillan (37)	1975	Midline of foot, inclined to the major axis of the ball

Not only does the attitude of the foot at contact seem important, but also does the position or attitude of the ball. The act of punting requires force transference from the swinging limb to the descending ball. Not only where the ball is contacted is important, but also how. In this respect the literature appears confusing. There was some agreement that the ball is angled slightly across the foot, but to what extent and what is an optimum is not made clear, or is not known at this time. This information is presented in Table 10.

Table 10

Ball Position at Contact

Author	Year	Implication
Pudlowski (46)	1959	Contacted 100-130 mm (4-5") from rear point
Young (64)	1959	Ball is flat; i.e. its long axis is parallel to the ground and pointing straight ahead or just slightly toward the inside
Miller (42)	1960	In line with foot
Allen (5)	1970	Ball placed flat on foot
Murray & Falcone (44)	1970	Ball pointed slightly inward
Alexander & Holt (2)	1974	24-25 degrees across the foot
Belichick (8)	1976	Long axis should extend from the big toe to the protruding bone on the right side of the ankle; the front of the ball 15 degrees lower than back
Hager (31)	1977	Slightly angled across body; laces on top and slightly to right

Miller (42) suggested that a punt kick spiralled because the ball was struck when at an angle across the foot. Obviously more research is needed to determine this angle and also the angle of the ball in relation to the horizontal.

Assuming a constant mass of the foot, it was popular to theorize that the maximum force imparted to the ball was predominantly attributable to the foot velocity. The *faster the foot* the *greater* the chance of good distance in the kick (based on $F = \frac{mv}{t}$, from Newton's Laws). There are very few studies that report on foot velocity in punt kicking. Table 11 shows these and also reports on the foot velocity in other types of kicking.

Table 11

Foot Velocity at Contact

Author	Year	Subject	Velocity, m/s
Roberts & Metcalfe (47) (place kick)	1968		18-24 (59-78 ft/sec)
Alexander & Holt (2)	1974	S1	24.4 (79.9 ft/sec) superior kick
			23.7 (77.6 ft/sec) average kick
		S2	20.9 (68.6 ft/sec) superior kick
			20.7 (67.9 ft/sec) average kick
Watson (59)	1974		31.4 (103 ft/sec)
Macmillan (37) (Australian punts)	1975	S1	23.3 (76.5 ft/sec)
		S2	23.4 (76.7 ft/sec)
		S3	23.7 (77.9 ft/sec)
Alexander & Holt (3)	1976	S1	24.9 (82 ft/sec) superior punt
			25.2 (83 ft/sec) average punt
		S2	19.5 (64 ft/sec) superior punt
			19.8 (65 ft/sec) average punt
		S3	22.5 (74 ft/sec) superior punt
			23.5 (77 ft/sec) average punt

The figures given in Alexander and Holt's study (2) suggest that there are other factors involved in a superior kick. The difference in foot velocity between a good kick and an average one is slight for both subjects. There was little difference among the three subjects reported by Macmillan (37). In Macmillan's study the average foot velocity was calculated for a drop punt, a drop kick and a stab kick, all of which are peculiar to Australian football.

It is generally acknowledged that the foot is plantar flexed in the act of kicking. The extent of this plantar flexion may determine, in conjunction with the ball drop position, the launch angle of the ball after contact with the foot.

Plagenhoef (40) reported a study where the kicker constantly punted further without his shoe on. Apparently he could not plantar flex his foot sufficiently with the shoe on, so there was a loss of force transmission when the impact took place.

Launch angle of the ball was reported in the first section of this chapter (Table 3). Forty to fifty degrees relative to the horizontal was suggested optimum angle range. Projectile theory has shown that an angle of 45 degrees is the optimum take-off angle resulting in a parabolic flight path of maximum horizontal distance.

The period after contact in a kick, or in any striking action, is termed the follow through. Although much has been written on the follow through in punt kicking, there is little agreement as to the role and function of this aspect of the kick. Follow through information is presented in Table 12.

Table 12

Follow Through

Author	Year	Comment
Mills (43)	1936	Responsible for distance
Summerall (58)	1968	In line with support leg
Kahler (35)	1969	Through the ball along the median line--not across
Bunn (13)	1972	Towards the opposite shoulder to produce spin on the ball
Storey (57)	1974	Limited--to keep support foot on the ground
Albright & Carlson (1)	1976	Lateral rotation, as evidenced by the foot turning out
Belichick (8)	1976	Foot should be above the head with the knee in front of the face
Cunningham (18)	1976	7 degrees medial rotation
Hager (31)	1977	Should be powerful enough to carry whole body off ground and turn it slightly to the left

With limited follow through there is the suggestion (57) that the support foot will (and should) stay on the ground in the punt kick. The relationship between the support foot and the kicking leg follow through has not yet been investigated fully.

Only Cunningham (18) reported ball aerodynamics as a determinant of the distance attained in a punt kick. In a later communication, Cunningham and Dowell (19) claimed that air resistance robs a punt kick of almost 50 percent of its potential distance. By applying the formula $R = KV^2 \sin 2\sigma/g$, they reported a constant (K) attributable to air resistance of 0.48 for Type I punts, 0.46 for Type II punts and 0.44 for Type III punts.

Other reasons advanced for gaining distance are listed below in Table 13. Again there was some disparity in the literature. This disparity manifested itself between those who have researched in biomechanics (2, 18, 19, 32, 37) and those who have observed kicking via coaching and teaching.

Table 13

Main Determinants of Distance Attained in a Punt Kick

Author	Year	Implication
Roberts & Metcalfe (47)	1968	Foot speed
Allen (5)	1970	The 'snap' in the kick
Bunn (13)	1972	Amount of knee flexion
Hay (32)	1973	Effective mass of the foot
Alexander & Holt (2)	1974	Effective transfer of force to the ball
Black (10)	1974	Leg power
Storey (57)	1974	Length of last step before contact
Macmillan (37)	1975	Foot contact
Cunningham (18)	1976	Establishing a punt whose long axis follows its trajectory

SUMMARY

Specialized research on punt kicking in American football was found to be extremely limited. Four outstanding studies have emerged over a span of 27 years: namely that by Smith (48) in 1949 where three kickers (expert, novice and average) were filmed at 48 frames per second (fps); that by Alexander and Holt (2) in 1974 where two expert Canadian kickers were filmed at 150 fps; that by the same authors (3) where three different Canadian kickers were, in 1976, filmed at 300 fps; and that by Cunningham (14) in 1976 where two Texas A & M varsity kickers were filmed at 200 fps.

As well as the above studies, the first part of the review included general literature on kicking. This review was chronologically ordered starting with the writing of Leroy Mills (43), a pioneer kicking coach in America, and concluded with the 1976 report by Alexander and Holt (3).

The second part of the literature review concerned itself with specific variables associated with punt kicking. Information from various sources regarding these variables was presented in tabular form. The following variables were included: number of approach steps, the role of the support foot, ball release from hands, height of ball at contact, kicking leg action, foot to ball contact, ball position at contact, foot velocity, ball launch angle and direction of the follow through. Opinion varied greatly for most of these variables.

A great many statements were encountered in this review concerning how to punt, but the supporting evidence lacked any research basis. Hay (25) pointed out areas of omission in the literature on kicking, namely, that very little is known of what muscle actions are used to bind the various body segments as a unit during the kicking act, and what is the contribution exacted from the ground via the non-kicking foot.

Cooper and Glassow (13) outlined a number of inadequacies in the kicking literature. They sought answers to questions such as: 'How far and at what angle should, or does, the ball drop in the punt kick?'; 'Why is ball velocity often greater than kicking foot velocity?'; 'What part of the foot contacts the ball, and what is the effect of any variation in this contact on ball velocity and accuracy?'.

Chapter 3

PROCEDURES

Cinematography was the basic research tool for this study. Normal filming guidelines were adhered to in obtaining the necessary film footage for a biomechanical analysis of the punt kicking skill. This chapter reports on all the procedures involved and is divided into the following categories: subject, subject preparation, filming procedures, film analysis, and analysis of data.

SUBJECT

The subject was a kicker from a team in the Big Eight Football Conference. Anthropometric data is presented in Appendix A. Segment lengths were obtained using a Siebner-Hiebner metric Anthropometer. The subject was considered to be in peak form at the time of the filming. He had undergone a long preseason conditioning program and had kicked a record distance field goal just one week prior to the filming. A copy of the subject informed consent is in Appendix F.

SUBJECT PREPARATION

Specific joint centers were marked with white tape to facilitate segmental analysis. Black dots were placed on the center of each marker. The joint centers marked are listed in Appendix B. The subject was as briefly attired as possible. He wore shorts, socks and his regular punting shoes, supplied by the Football office as suitable for the artificial turf surface. Identification markers were also applied on the support leg and the left arm as illustrated in Figure 6.

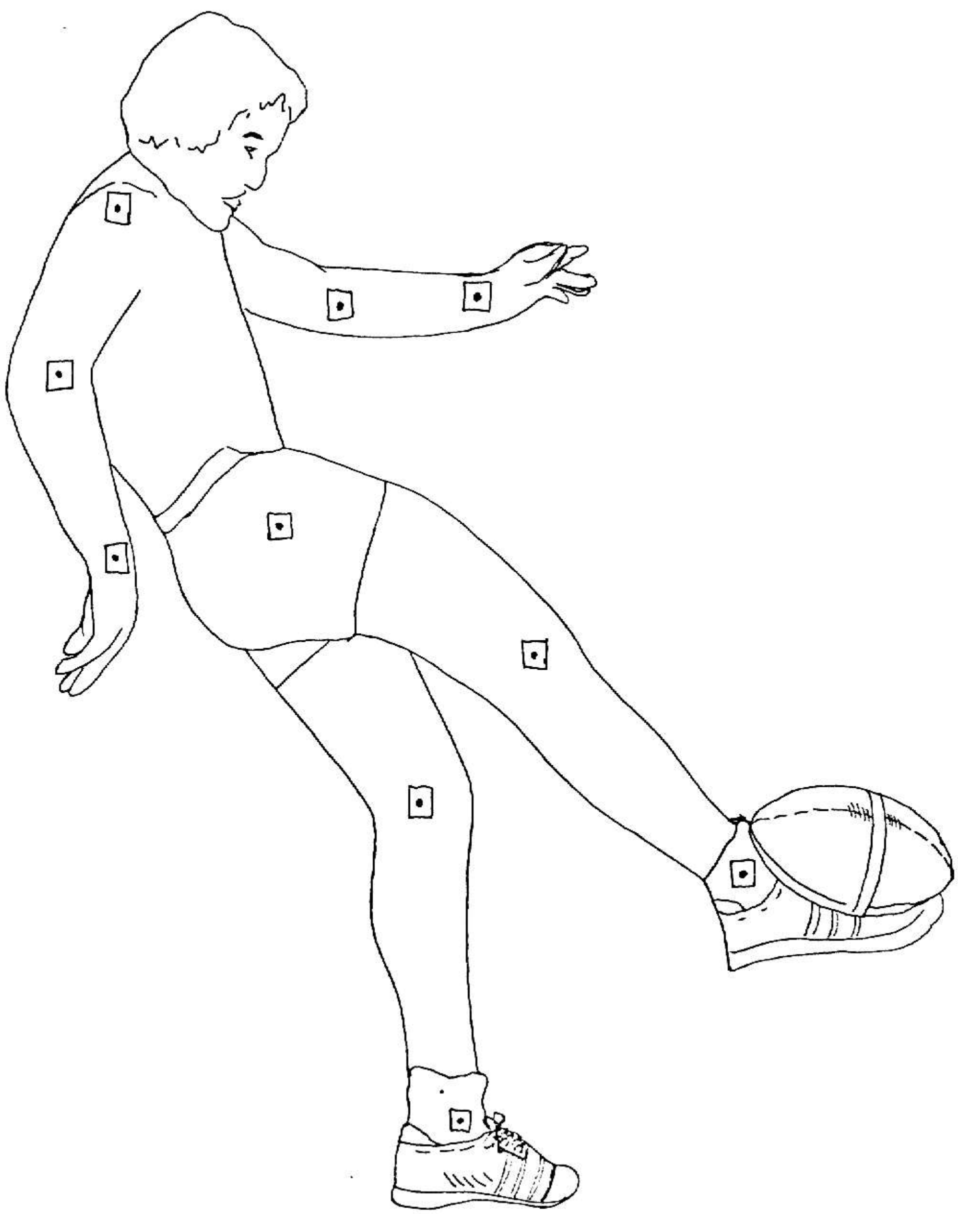


Figure 6

Joint Center Markings

Tuff-skin was applied to the surface of the skin to ensure maximum marker adhesion. Because of the nature of the activity under study, there was some movement of the skin about some joints, especially the knee. This was taken into account in the film analysis and the marker references were not used in specific cases. The anatomical landmark of the bony prominence was visually centered. Also, the crotch, tip of the sternum and the tragus of the ear were visually centered.

The subject was warmed up and stretched up to the extent of a normal pre-game conditioning. A number of practice kicks were allowed to condition the specific kicking muscles and to familiarize the subject with the filming environment.

FILMING PROCEDURES

The subject punt kicked the ball for maximum distance (see Appendix D for the record of all trials). A line at the front of the north end zone was used as the kicking site. An additional tape marking perpendicular to this line was also used as a guide to the kicker. The subject displayed great uniformity in the approach and kicked each time from the designated spot. The subject received the ball from a center snap. The filming was completed in sunny conditions and with little or no wind prevailing.

Each kick was measured from the designated spot to the point of landing. This measure, to the nearest yard, was made using the yard hash marks on the artificial turf surface. Hang time and the time from the catch to visual ball release from the foot were recorded by assistants using Hanhart DGBM 7016 145 stopwatches. Time and distances are recorded in Appendix D. Two Spalding J5V footballs inflated to 90,000 Nm^{-2}

(13 lbs/sq inch) were used.

A tripod mounted 16 mm Red Lakes Laboratory Locam Camera (model 51-0002), operating at 500 frames per second, was used to record all the performances in the sagittal plane. Kodak Tri-X High-Speed Film, type 7277, rated at 400 ASA was used. The cinematographical record sheet is supplied in Appendix E. The camera was checked for horizontal and vertical attitude by the use of a spirit level. Light measures were taken with a Weston Master 6 Light Meter. As the natural light conditions remained constant no further check was made as the filming proceeded. A one-hundredth of a second clock was placed in the camera view, as well as the subject and trial identification numbers. All filming was done outdoors in the KSU Football Stadium. The kicking surface was Astro-turf. To allow the camera (electrically driven) to reach its set frame rate it was started as the ball was snapped to the kicker. It was turned off after the peak of the follow through had been reached. Two views of the filming environment are shown in Figure 7.

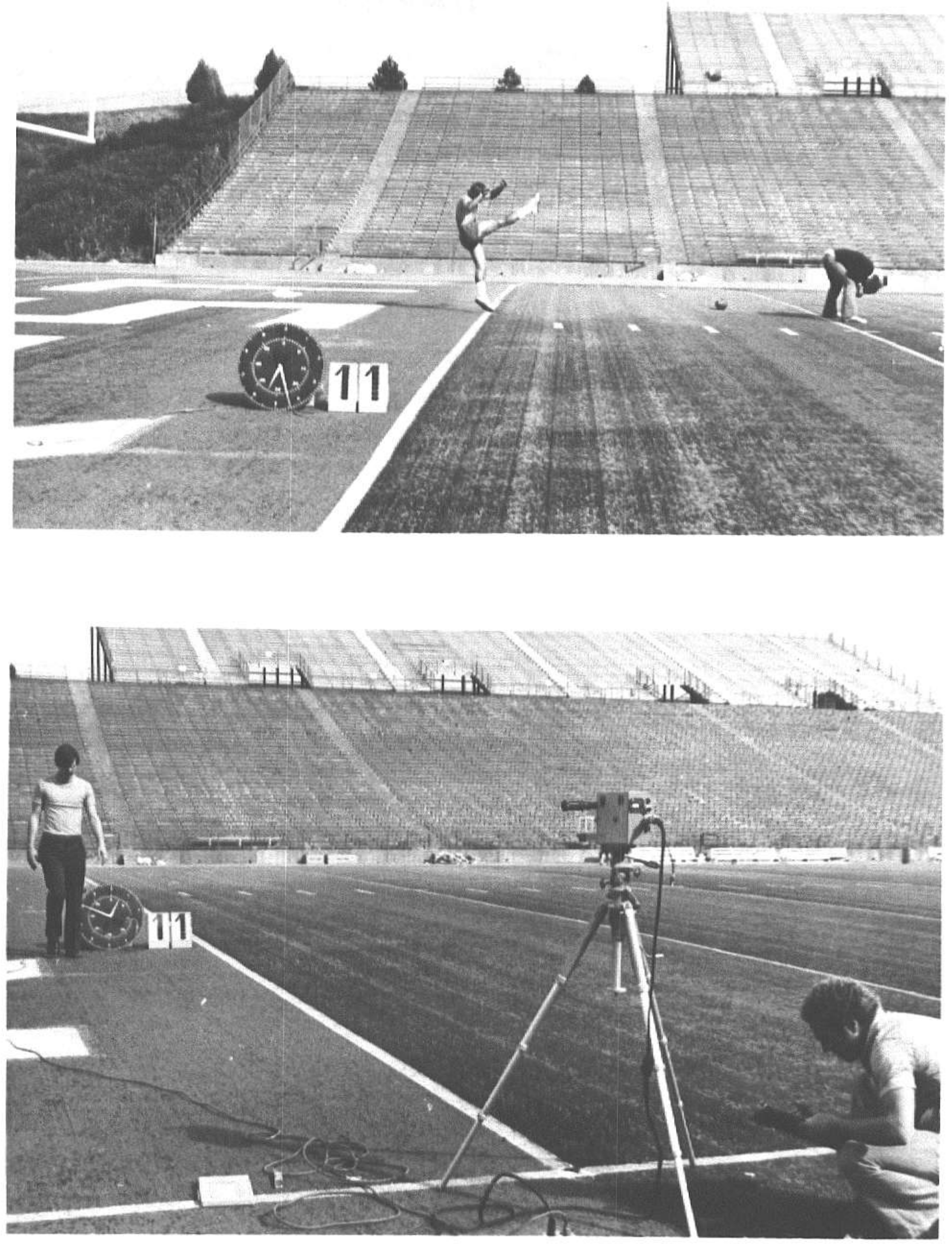


Figure 7

Filming Environment

FILM ANALYSIS

Nineteen segmental coordinates (from the points listed in Appendix C) were obtained using a Vanguard Motion Analyzer and a Hewlett-Packard Digitizer linked on-line with a paper tape punch and automated teletype printer. This equipment was located in the Biomechanics Laboratory at the University of Iowa and was made available through the courtesy of Dr. James G. Hay. Financial assistance for the analysis was made available through the Graduate Office of Kansas State University.

Fifty-one frames per trial were analyzed. Every fourth frame from ball release from the hands was selected for analysis. This gave a constant time factor of 0.008 seconds between analyzed frames. The film rate of 500 fps was checked using the clock in the camera view.

Special positions, such as heel strike, ball contact, ball release from the foot, support foot lift and a position of 40 frames later were also analyzed. Coordinates were established for the ends of the football at each of these positions, with the exception of the last mentioned. At this time the ball was out of the camera view. End coordinates of the ball enabled the calculation of the ball angle to the horizontal.

ANALYSIS OF DATA

A computer purifying program was used to detect any major coordinate discrepancies. This program listed the X & Y coordinates of the reference points and the differences between consecutive coordinate values. The latter were multiplied by 100 to facilitate inspection. All film data was subjected to this program and digitizing errors were corrected using a *trend* averaging procedure. Most of the small number of corrections made involved the Y coordinate for the left hand extremity. This was the last segment analyzed. The problem arose from an operating error. The last coordinate was cancelled by the new card instruction before it could be punched or typed.

The Wildcat biomechanics computer program was used to reduce the data. The center of gravity of the body was calculated using segmental data according to Dempster (21). Center of gravity displacement and the velocity of limb segments were also calculated in horizontal, vertical and linear directions.

Velocities of selected limbs and the center of gravity displacements were plotted by computer using the Calcomp Plotter in conjunction with the IBM 370/158 Computer in operation at Kansas State University.

Ball velocity and ball attitude were calculated using the coordinates of the extremities of the ball. A Texas Instruments SR-10 hand calculator was used. Horizontal ball velocity was calculated by subtracting the X coordinates and multiplying by 1.05 (the image to real life multiplier) and dividing by the time elapsed between respective frames. Vertical velocity was calculated in similar fashion by subtracting the Y coordinates. Linear velocity of the ball was the square root of the total of the horizontal and vertical velocity each squared.

Angle of the ball relative to the horizontal was calculated by using the tangent theorem. The difference in the Y coordinates over the difference in the X coordinates was equal to tan of the angle. This was calculated at four specific phases in the kick (release from the hands, contact, release from the foot and in flight). The flight angle of the ball was established by dividing the vertical velocity of the ball by the horizontal velocity. This was tan of the angle of the velocity vectors.

Contact time between the foot and the ball was established by counting the number of frames from first contact till obvious release from the foot. The number of frames was then multiplied by 0.002 seconds; that is the constant time interval between each frame.

Ball height from the ground was calculated by subtracting the Y coordinate of the center of the ball (established by taking the mean of the end coordinates) from the Y coordinate of the left toe (or ground actually) and multiplying this by the constant 1.05 to establish the real distance.

Using distance as the criterion variable, correlations, means and standard deviations were calculated using a Stepwise Statistical computer program. This program, with alpha set at 0.05, 'dropped out' variables leaving either a significant, or close to significant single variable. All variables were correlated with distance in groups of five and then regrouped based on the correlation and its significance level.

SUMMARY

A kicker from a team in the Big 8 Football Conference was filmed outdoors at 500 fps using a Red Lakes Laboratory Locam Camera. Twelve trials were analyzed with a Vanguard Motion Analyzer, a digitizer linked with an on-line paper tape punch and automated teletype printer. The film data was further reduced by computer using the 'Wildcat' biomechanics Fortran program (see Appendix P).

Chapter 4

RESULTS AND DISCUSSION

The purpose of this study was to establish, by cinematographical analysis, biomechanical parameters of punt kicking an American football. The results of the study are reported under two main divisions: one, biomechanical parameters from the total number of trials, using the specific kicking variables (Figure 5) as the focus of attention; and two, a comparison between a superior and an inferior kick in the study. The discussion deals mainly with this latter aspect, in an attempt to isolate from the biomechanical parameters specific factors associated with superior performance.

BIOMECHANICAL PARAMETERS

This section contains all results found on the approach, the role of the support foot, the method and timing of release, and at contact: height of the ball from the ground, kicking leg action, foot to ball contact, ball position relative to the foot, foot velocity, ball velocity, ball launch angle, and the direction of the follow through and the action of the support leg at this time. Limb segment velocities are also presented.

Approach

The subject started from rest in all trials filmed. He took two steps in completing each kick. After receiving the snapped ball and adjusting the ball to a laces-up position, he stepped off on his right (kicking) foot. While the support foot was still being brought forward, the ball was released. The heel of the support foot was planted first. Then, as the body was brought forward over the support leg, the support foot came into full contact with the ground.

The subject demonstrated remarkable ability in receiving the snapped ball. Although the snap was straight, the ball height varied from the kicker's knees to his face. Once he had caught and controlled the ball it took, on average, 0.144 seconds to get the ball into his desired laces-up position. This was prior to any other body movement. Comments regarding the snapped ball are listed in Appendix K. Total time from the catch to the completion of the kick, recorded by an experienced observer using a stop watch, ranged from 1.3 to 1.6 seconds ($\bar{x}$ = 1.46 secs). A more detailed kick-time analysis is in Appendix L.

Observation of the film showed that he had a consistent approach pattern. He was able to kick each time on the designated end-zone line which was in the center view of the camera. Total distance involved in the approach was 2.6 meters (8.5'): see Figure 8.

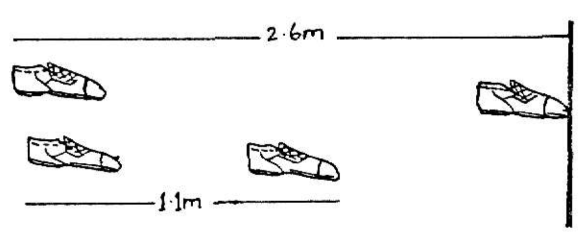


Figure 8

Two Step Punting Approach

He took steps of mean 1.3 meters in the kick approach (usual walking stride for a male is approximately 1 meter). The approach was a fast stride action with the left (support) foot stride being an average 0.4 meters longer than the initial step-off onto the right foot (1.1m).

Role of the Support Foot

No quantitative data was collected on the left (support) foot. Observation of the film showed that the left foot was placed in line with the body and that the momentum generated by the kicking leg was sufficient to cause the entire body to lift off from the ground.

In human physical performance the body exerts a force against its environment. In the skill of kicking some force is expressed downward through the support leg. This force has not yet been reported in the literature. Various opinions as to the role of the support foot are presented in Table 5.

Film results of this study showed that the support foot appeared to be parallel with the body and to be in line with the intended direction of the kick. This implication was in accord with that suggested by Kahler (35). Front-on pictures from a similar, unfinished study has given evidence that the support foot may actually be placed towards the mid-line of the body. More research is needed on this aspect.

Ball Release

The ball was released prior to the support foot heel being planted. The time lapse between release and support foot heel plant averaged 0.138 seconds (see Appendix L). The left hand was withdrawn from the ball first; approximately 0.10 seconds later the right hand was withdrawn. Free fall time for the ball is in Appendix L. The mean free fall time was 0.29 seconds, with a range of 0.26 to 0.32 seconds. This accounts for approximately 20 percent of the total kick time. During this time the only contact the kicker had with the ball was visual. By visual stimuli he was able to adjust the timing of the kicking leg, but the flight path of the ball to the foot already was determined.

The distance the ball dropped from final right hand release to contact is presented in Table 14; see Appendix G. The mean ball drop distance was 0.57 meters. The range, standard deviation, and correlation with the distance achieved in the kick are listed in Appendix M.

The angle of the ball in relation to the horizontal plane was not calculated at the moment of release. It was calculated at heel strike some 0.14 seconds later. At this time the end coordinates of the ball were not obscured by either the subject's hand or forearm. The results are listed in Table 15; see Appendix H. The mean ball angle to the horizontal at heel strike was 18.6 degrees, with 6.9 degrees standard deviation.

The vector velocity angle of the football at heel strike provided more information about the ball release. This information is in Table 16; see Appendix I. The mean for this angle was 42.7 degrees. The angle correlated 0.55 with distance achieved; this correlation was almost significant ($p \leq .07$). The standard deviation was only 2.6 degrees. This reflects the consistency in the basic kicking pattern that the subject possessed. It may also indicate that this angle alone is not solely responsible for achieving maximum distance in a kick.

Contact

At contact, the ball angle relative to the horizontal had changed. Table 17 lists these angles and also shows the difference in degrees from that at heel strike.

Table 17

Angle of the Ball at Contact

Trial Number	Degrees*	Change from Heel Strike
1	25	(+3)
2	18	(-4)
3	-6**	(-17)
4	12	(-14)
5	9	(-4)
6	5	(-6)
7	22	(-3)
8	8	(-8)
9	19	(-1)
10	10	(-9)
11	23	(-7)
12	2	(-6)
$\bar{x}$	12.3	
SD	9.4	

*relative to the horizontal

**negative means the rear tip of the ball was depressed.

The change in attitude of the ball implied that the kicker did something to the ball during or at the final instance of release. If the ball was merely dropped it should have stayed at the same angle relative to the horizontal. The kicker may have done the following;

1. Pushed down on either the front of the ball, or on the back of the ball (as in Trial 1), or,

2. Not simply dropped the ball but projected it forward creating a flight path that, in conjunction with air resistance factors and gravity, brought about some alteration in the spatial attitude of the ball between release and contact.

What was clear from the film was that, in addition, the ball underwent some form of rotation about its long axis from the time of release to the time of contact. This was evident by observing the laces of the ball. At release they were in a top position, while at contact they were to the right a varying number of degrees. This is evident in Figures 9 to 11. This rotation had to be initiated by the kicker.

Although the ball was considered to be dropped at release from the hands, it was moving at the same speed as the subject's hands when released. Results showed that at contact, the ball, with two slight exceptions, was moving horizontally faster than the center of gravity of the subject. These results are shown in Table 18.

Table 18

Horizontal Velocity of Subject Center of Gravity and Ball at Contact

Trial Number	Subject C of G (m/s)	Ball (m/s)	Difference
1	3.2	3.1	-0.1
2	1.3	3.0	+1.7
3	1.8	2.7	+0.9
4	1.2	3.0	+1.6
5	1.8	3.2	+1.4
6	1.8	2.8	+1.0
7	1.6	3.2	+1.6
8	1.6	3.4	+1.8
9	3.5	3.4	-0.1
10	0.8	3.1	+2.3
11	2.5	3.1	+0.6
12	2.2	3.1	+0.9
$\bar{x}$	1.9	3.1	+1.1
SD	.8	.21	.6

Table 18 indicates that the subject may actually have pushed the ball slightly forward at release. If the ball was dropped from a stationary position it would probably have contacted the thigh region of the kicking leg. Linear velocity at contact (Appendix M) for the above also supported this contention. In all trials the linear velocity of the ball was greater than that of the subject center of gravity; see Table 19.

Table 19

Linear Velocity of Subject Center of Gravity and Ball at Contact

Trial Number	Subject C of G (m/s)	Ball (m/s)	Difference
1	3.9	4.2	+0.3
2	1.4	4.0	+2.6
3	1.9	3.9	+2.0
4	4.0	4.2	+0.2
5	2.4	4.3	+1.9
6	1.9	4.0	+2.1
7	2.5	4.3	+1.8
8	2.7	4.3	+1.6
9	4.1	4.4	+0.3
10	2.2	4.2	+2.0
11	2.9	4.2	+1.3
12	2.7	4.3	+1.6
$\bar{x}$	2.7	4.2	+1.5
SD	.9	0.15	.7

The mean linear velocity of the ball was influenced by its downwards motion. The mean vertical velocity for the ball was -2.8 m/s. This velocity was negative because the ball was falling. The subject center of gravity was not falling as such, although it did undergo minor vertical velocity fluctuations during the time from ball release to contact. The vertical velocity of the subject's center of gravity was always positive at contact. Velocity mean was 1.3 m/s with standard deviation 0.6; see Appendix N. This suggests that following a general depression of the body's center of gravity, coinciding with the kicking leg being flexed and starting to swing forward, the kicker was experiencing some upward motion as the kicking leg went past the perpendicular and was reaching the point of contact, some 0.38 meters (15") above the ground.

Ball Height at Contact

Ball height from the ground at contact varied only slightly throughout the twelve trials. The results are listed in Table 20. This height was measured from the mean point of the end coordinates to the ground. This mean point was the best available estimate for the center of the ball.

Table 20

Ball Height at Contact

Trial Number	Height, meters		% of Knee Height
1	.36	(14.2")	72
2	.39	(15.4")	78
3	.39	(15.4")	78
4	.38	(15")	76
5	.37	(14.5")	74
6	.36	(14.2")	72
7	.40	(15.75")	80
8	.38	(15")	76
9	.42	(16.5")	84
10	.39	(15.4")	78
11	.36	(14.2")	72
12	.36	(14.2")	72
$\bar{x}$	.38	15"	74
SD	.02		

The mean ball height was 0.38 meters, with a range of 0.06 meters, standard deviation 0.02, and a non-significant correlation of -0.42 ($p \leq 0.17$) with distance. This finding tended to suggest that a maximum distance achieved in a kick would be associated, but not strongly, with a height above the ground at contact of less than the mean found in this study. The ball height figures from this study were in agreement with those presented by Allen (5), Bunn (13), Fuoss (28) and Hay (32). Leg limb lengths may be an influencing factor in determining this parameter of a punt kick. Also critical may be the amount of knee flexion of the support leg and the amount of backward upper body lean at contact. These angles are presented in Table 21.

Table 21

Selected Body Angles at Contact*

Trial Number	Support Leg Knee Flexion, degrees**	Upper Body Lean Backward, degrees***
1	61	66
2	60	67
3	63	64
4	58	65
5	57	65
6	63	66
7	60	64
8	60	61
9	62	65
10	62	65
11	61	62
12	60	65
$\bar{x}$	60	65
SD	1.8	1.7

*Measured by protractor from still contact pictures.

**Measured posteriorly to a horizontal line drawn through the knee joint.

***Measured posteriorly to a horizontal line connecting the right hip and shoulder joint.

These data reflected little variation over the twelve trials and confirmed the overall film impression of a consistent gross movement pattern in punt kicking.

<u>Ball Position Relative to the Kicking Foot</u>

The ball drop was considered by several authors as a most important aspect of punt kicking (2, 3, 8, 31, 35, 44, 46). Underlying this importance is the need for a kicker to get the ball to an optimum position at contact. Examples of ball position at contact from this study are presented in Figures 9 to 11. From left to right the numbers in the figures refer to the subject number and then the trial number. Trial 10 was represented by a zero.

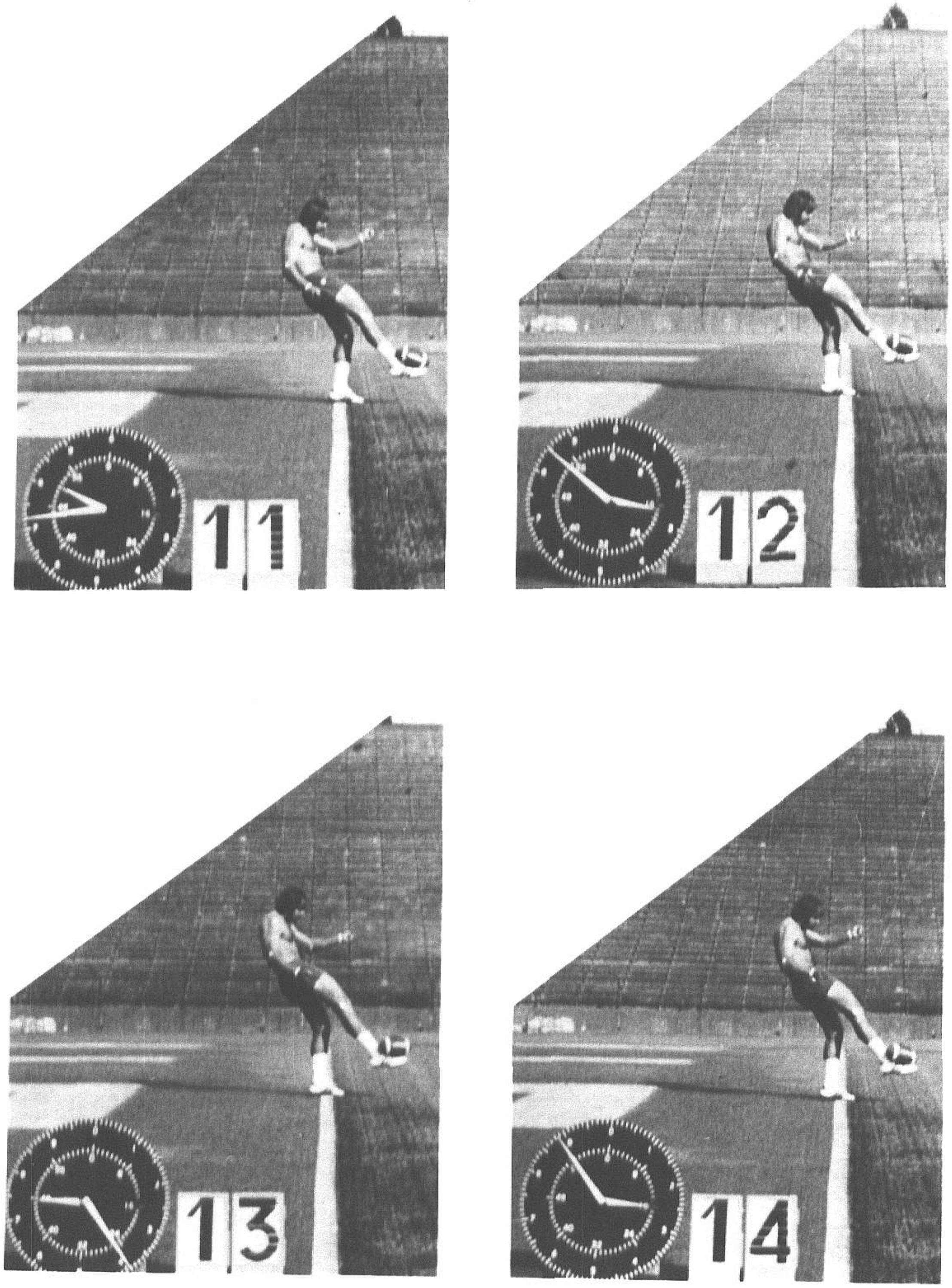


Figure 9

Contact Frames for Trials 1-4

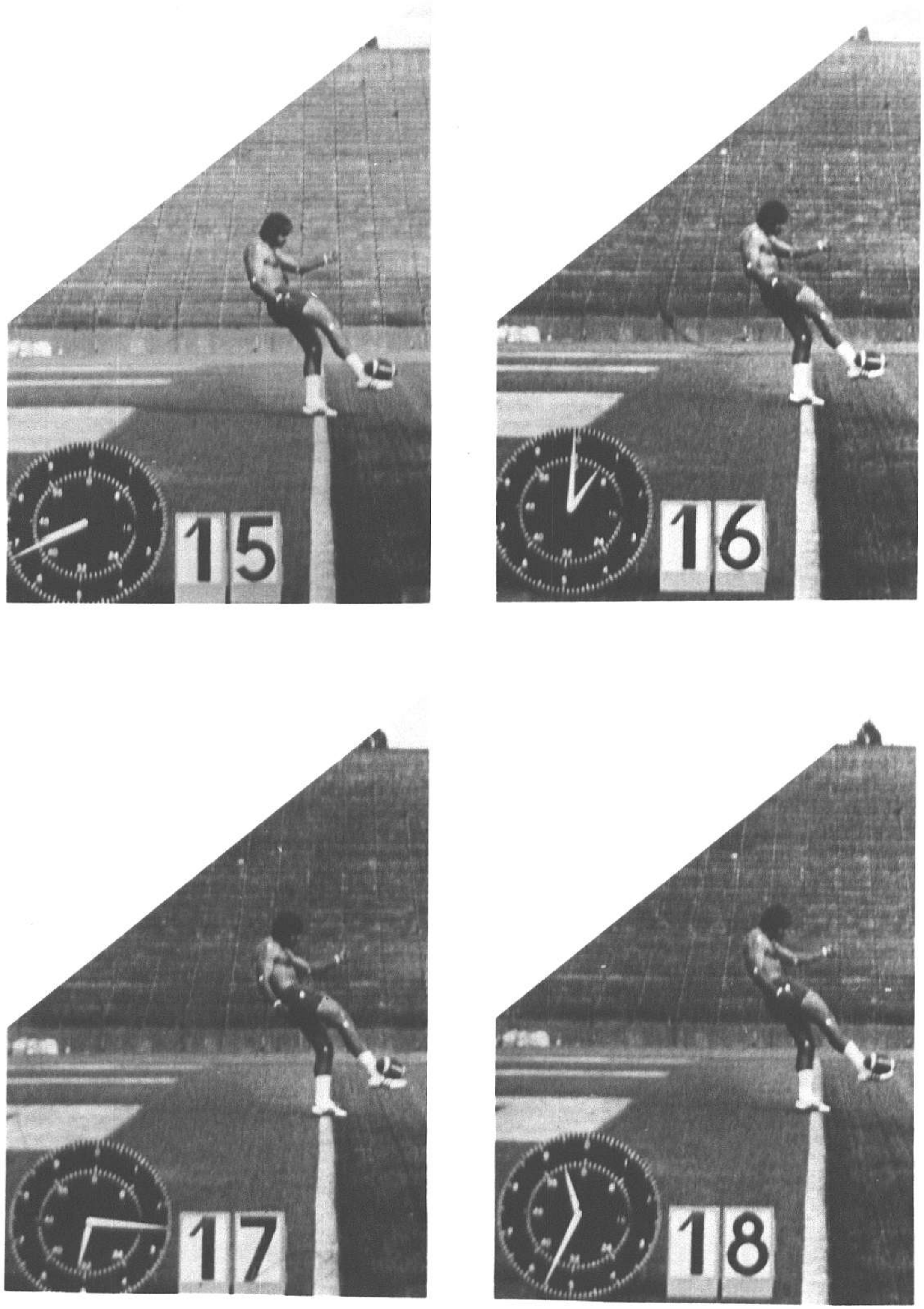


Figure 10

Contact Frames for Trials 5-8

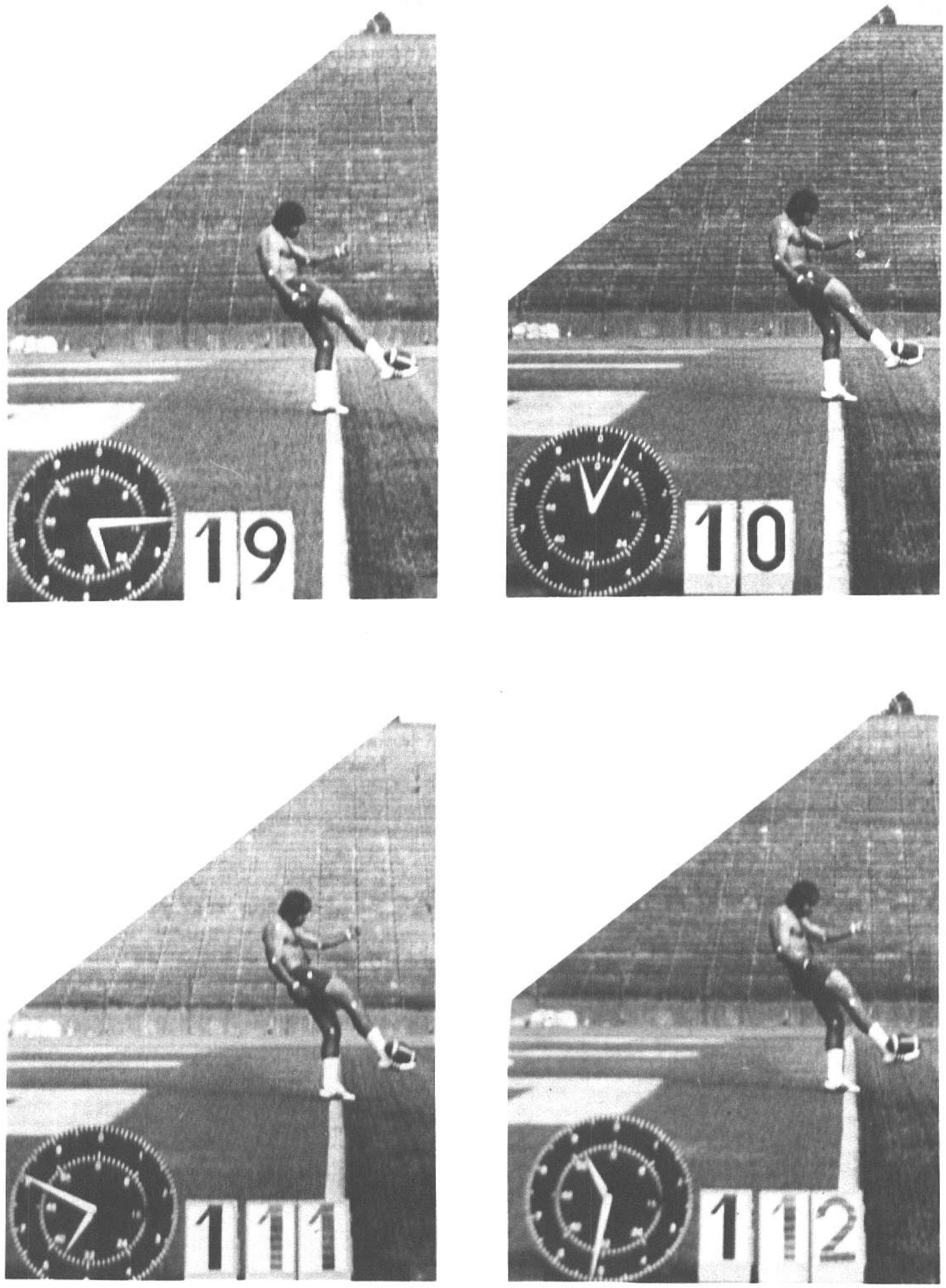


Figure 11

Contact Frames for Trials 9-12

The ball angle in the sagittal plane varied at difference stages of the kick. At heel strike and ball contact, with two exceptions (denoted as being negative), the front tip of the ball was lower than the back. In the two other stages the front tip of the ball was higher than the back (again with the exceptions denoted as being negative). These angles are presented in Table 22.

Table 22

Angle of Ball at Selected Stages of Punting, degrees

Trial #	Heel Strike	Ball Contact	Ball Launch	In Flight (at support foot lift)
1	22	25	14	25
2	22	18	19	52
3	11	-6	-5	32
4	26	12	6	30
5	13	9	15	21
6	11	5	4	0
7	25	22	19	34
8	16	8	4	-32
9	20	19	7	-13
10	19	10	9	19
11	30	23	17	-22
12	8	-2	-10	-40
$\bar{x}$	18.6	12.3	9.0	7.1
SD	6.9	9.4	7.9	31.3

At contact the ball angle varied from -6 to 25 degrees. Trials 12, 6 and 8 were closest to horizontal which was the optimum position suggested by Allen (5) and Young (64). Belicheck (8) suggested that the front of the ball be 15 degrees lower than the back. The average angle in this study was 12 degrees lower.

It was evident from Figures 9 to 11 and from the ball X-coordinates difference (Appendix O) that the ball was angled across the foot at contact. Alexander and Holt (3) claim that 25 degrees is the optimum angle. They claimed that this angle across the foot prevents the tips of the ball making premature contact and ensures that the ball is allowed to roll off the foot and create a spiral. In all of the trials in this study the ball spiralled.

Foot to Ball Contact

The exact nature of the foot to ball contact was not established in this study. Figures 9 to 11 showed that the ball was generally struck high on the foot. This anterior distal aspect of the ankle was shown by Alexander and Holt (2,3) to be the optimum area of contact. Bunn (13), Fuoss (28) and Kahler (35) also supported this view. The contact figures also reflected a deal of variation in the angle of the ball. These angles were presented in Table 22. Trials 3 and 12 were exceptional in that the rear tip of the ball was lower than the front at contact.

In eight trials the kicker's foot was horizontal at contact. In the other four trials (8, 9, 10, 12) the heel was lower than the toe at contact. Variation ranged from 6 to 8 degrees from horizontal. In all cases the results were contrary to the writing of Murray and Falcone (44) who claimed that the toes should be pointed down at contact. Trial 10 was the poorest of the series in terms of distance. Trial 12, though, was above the mean.

Alexander and Holt (3) claimed that contact should be made through the center of gravity of the ball. Using the results of this study, an attempt was made to demonstrate this. By assuming that the mean of the end coordinates of the ball was the center of gravity of the ball, and using the center of gravity data for the foot segment, it was found that on average the ball was struck approximately 30 mm (1.2") behind its center of gravity. These results are listed in Table 23.

Table 23

Center of Gravity Difference Between Foot and Ball at Contact

Trial Number	Difference mm
1	31.5
2	21.0
3	59.0
4	35.2
5	31.5
6	40.9
7	17.8
8	39.9
9	16.8
10	26.3
11	31.5
12	29.4
$\bar{x}$	30.9
SD	9.5

These results should be taken with caution though. Appendix O lists the ball end X-coordinates difference at contact. This difference implied, and the Figures 9 to 11 confirmed, that the ball was contacted when at an angle across the foot. The mean difference between the recorded length of the football at contact and its actual length was 27.4 mm (1.1"). This finding suggested that the ball was actually struck in an area that corresponded closely to its center of gravity. The main difference then was that the variation expressed was about the center of gravity of the foot segment.

Foot to ball contact time was extremely short in this study. Previous studies (2, 47) had suggested a contact time of 0.014 and 0.015 seconds. The mean contact time in this study was 0.008 seconds. The results are listed in Appendix L. The difference in contact time may not have only been a difference in subjects, but may have been linked with the difference in filming speed in the studies. Alexander and Holt (2) used 150 fps, Roberts and Metcalfe 64 fps, while 500 fps was used in this study. This gave the ball in contact with the foot for three to five frames whereas using a slower speed, especially 64 fps, the contact time would have to be approximated.

Kicking Foot Velocity

These results are listed in Table 24 and 25. Velocities are presented for vertical, horizontal and linear directions of the right toe extremity and the linear velocity of the ankle.

Table 24

Right Toe Velocities at Contact

Trial Number	Horizontal, m/s	Vertical, m/s	Linear, m/s
1	21.5	17.3	27.6
2	21.8	19.0	28.9
3	19.2	16.3	25.6
4	20.7	15.4	26.2
5	21.8	16.0	27.5
6	21.6	14.9	25.3
7	20.9	17.3	23.0
8	19.3	15.7	24.9
9	19.4	19.6	27.6
10	18.9	18.3	26.3
11	13.1	14.8	19.8
12	18.6	18.0	26.3
$\bar{x}$	19.7	16.9	25.7
SD	2.4	1.6	2.4

The mean linear velocity of the right toe (25.7 m/s) was in accord with the figures presented by Alexander and Holt (3) for subject 1 in their study, but was higher than that reported in other studies (2, 37, 47).

Ankle joint velocities generally were slower than those for the right toe. The difference was due to the toe extremity travelling a greater arc distance per unit of time than the ankle joint. Linear velocities of the ankle joint are presented in Table 25: see Appendix J. The mean velocity here was 18.5 m/s, with a standard deviation of 1.0 m/s.

In all trials the peak linear velocities for both the right toe extremity and the ankle joint were reached prior to contact. This corresponded with the work of Plagenhoef (45) who found that peak velocities were reached when the lower leg was perpendicular to the ground. Obviously there had to be some compromise between peak velocities of the lower limb segments and the point of contact with the ball.

As listed in Appendix M, there was no significant correlation ($p \leq 0.05$) between distance achieved and any of the following results: right toe extremity velocities, ankle joint linear velocity or peak linear velocities for both. This tends to contrast with the reported findings of Allen (5), Black (10), Bunn (13) and Roberts and Metcalfe (47) who all claimed that foot speed was the critical aspect in determining distance in a punt kick. The results of this study tend to confirm the work of Alexander and Holt (3) who reported on a Canadian kicker who generated greater foot velocity in an average punt than in a superior one.

Although conclusive evidence is lacking, it appeared that foot contact with the ball and the position of the ball relative to the foot was more important as regards distance than foot speed. Alexander and Holt (2,3), Hay (32) and Macmillan (37) also support this theory.

Ball Velocity at Launch and In Flight

Roberts and Metcalfe (47) reported that when contact was good in punt kicking the ball speed was 5 to 7 m/s faster than the foot. The results of this parameter in the study are shown in Table 26.

Table 26

Linear Ball Velocity at Launch and in Flight*

Trial Number	Launch, m/s	In Flight, m/s	Difference, %
1	21.2	29.0	37
2	26.1	28.6	10
3	20.7	28.5	38
4	24.2	28.8	19
5	23.9	29.4	23
6	24.3	28.9	19
7	21.8	29.2	29
8	27.0	29.1	8
9	26.2	29.1	11
10	28.6	25.7	-6
11	26.2	29.7	13
12	27.1	28.9	7
$\bar{x}$	24.8	28.7	16
SD	2.5	1.0	

*At the time of the support foot lift from the ground. Actual times are recorded in Appendix L.

The mean linear velocity of the right toe extremity was 19.9 m/s at ball launch and 9.2 m/s just prior to the time of the support foot lift from the ground. The latter velocities were recorded from the fifty-first analyzed frame. Support foot lift was just after this, an average of 0.03 seconds later. Support foot lift toe velocities would have been slightly slower as the entire kicking leg was decelerating. The findings tended to support Metcalfe and Roberts (47) in that the linear ball velocity was greater than the linear toe velocity by approximately 5.0 m/s at launch. The reason for this is not understood (17). As no further contact is made with the ball after its launch from the foot, it may be that aerodynamic factors and the coefficient of restitution of the ball combine to bring about this increase in linear velocity. Plagenhoef (45) reported a coefficient of restitution for a football dropped on a timber surface of 0.7. This figure implied high elastic properties associated with an American football.

By dividing the ball linear velocity at launch by the linear velocity of the right toe at contact, a "restitution" ratio was established. However the ball was not stationary at contact. By subtracting the linear velocity of the ball at contact from the launch velocity another ratio was established. These results are presented in Table 27.

Table 27

"Restitution" Ratio of the Ball

Trial #	Linear Ball Velocity at Launch:A	Linear Rt. Toe Velocity at Contact:B	"Restitution Ratio":C	Linear Ball Velocity at Contact:D	A-C	D÷B Ratio
1	21.2	27.6	0.77	4.2	17.0	0.62
2	26.1	28.9	0.90	4.0	22.1	0.76
3	20.7	25.6	0.81	3.9	16.8	0.66
4	24.2	26.2	0.92	4.2	20.0	0.76
5	23.9	27.5	0.87	4.3	19.6	0.71
6	24.3	25.3	0.96	4.0	20.3	0.80
7	21.8	23.0	0.94	4.3	17.5	0.76
8	27.0	24.9	1.08	4.3	22.7	0.91
9	26.2	27.6	0.95	4.4	21.8	0.79
10	28.6	26.3	1.08	4.2	24.4	0.93
11	26.2	19.8	1.30	4.2	22.0	0.90
12	27.1	26.3	1.03	4.3	22.8	0.86
$\bar{x}$	24.8	25.7		4.2		0.79
SD	2.5	2.4		0.15		

The final "restitution" ratio had a mean of 0.79. This approximated the figure reported by Plagenhoef (45) but with such a small number of trials no definitive conclusions were made.

It was found in this study that the football revolved on average seven times per second. There was very little reported regarding the aerodynamics of a football. Mills (43) referred to the ball as a prolate spheroid. Cunningham and Dowell (19) suggested that air resistance factors reduce the possible distance achieved in a punt kick by 50%. Using their formula of $R = \frac{V^2 \sin 2\sigma}{2g}^*$ the following results were calculated.

Table 28

Actual and Calculated Punting Distances

Trial Number	Actual Distance	Calculated Distance*	Ratio
1	51.6	42.8	0.83
2	54.8	39.2	0.71
3	52.1	40.5	0.77
4	56.7	42.1	0.74
5	46.2	43.4	0.94
6	61.2	42.3	0.69
7	52.1	42.5	0.82
8	51.2	42.8	0.84
9	47.5	38.1	0.80
10	43.9	31.2	0.71
11	52.1	44.9	0.86
12	55.7	41.3	0.74
$\bar{x}$	52.1	40.9	0.78
SD	4.7	3.6	

In all trials the formula underpredicted the range of the kick. It appeared that other unexplained factors contributed to an extended time of the ball in the air and consequent greater distance gained. The calculated distance had a correlation of 0.48, ($p \leq 0.11$) with distance. The components of the formula (launch angle and ball velocity at launch) each had a negative correlation with distance of -0.35 and -0.21 respectively. They had a stronger negative correlation with the predicted distance (-0.66, -0.46). This may have been brought about by the involvement of sine of the launch angle. The optimum launch angle for maximum distance is 45 degrees. In all trials the launch angle was greater than this. Inspection of Cunningham and Dowell's formula (19) showed that for a given velocity V, the distance is a maximum when sine 2σ is a maximum. Since the sine has its maximum value of unity for an angle of 90 degrees, the angle σ had to be 45 degrees. Furthermore, the range for any projectile will be the same for a corresponding number of degrees above and below the optimum of 45 degrees (assuming a constant launch velocity).

Ball Launch Angle

Launch angle results were presented in Table 22. These angles represented the relationship of the ball to the horizontal immediately after the ball was clear of the foot. The launch angle ranged from -10 to 19 degrees. Correlation statistics are presented in Appendix M.

Vector velocity angles, calculated from the horizontal and vertical ball velocity at launch and in flight, are presented in Table 29.

Table 29

Vector Velocity Angle of Football at Launch and In Flight

Trial Number	Launch, degrees	In Flight, degrees
1	47	51
2	55	52
3	51	53
4	48	50
5	50	50
6	48	46
7	39	47
8	49	47
9	59	53
10	56	49
11	47	46
12	52	52
$\bar{x}$	50.1	49.7
SD	5.2	2.6

Trial 6 appeared closest to the optimum angle. The ball was in line with the horizontal at this time. However neither of the above angles correlated significantly with distance (r = -0.35, and -0.20).

Kicking Leg Action

Figures 9 to 11 showed that the kicking leg was almost straight at contact in each of the trials. Kicking leg knee angles are reported in Table 30.

Table 30

Kicking Leg Angle at Contact

Trial Number	Angle, degrees*
1	174
2	173
3	172
4	170
5	170
6	169
7	162
8	173
9	170
10	176
11	162
12	173
$\bar{x}$	170
SD	4.2

*Measured relative to a straight line bisecting the knee and ankle joints.

The above data supports that reported in the literature (17, 29, 35, 61). The results also showed that extension of the lower leg was the major joint action contributing to foot velocity in the kick. This too supported other findings (11, 13, 17, 47).

Right knee velocity just prior to contact is included in Appendix M. Right hip velocity just prior to contact was also considerably less than knee, ankle or toe velocities ($\bar{x}$ = 8.0 m/s). With the exception of trial 11, peak knee velocity of the kicking leg was approximately 13 m/s. This was, on average, 7 m/s slower than the peak right ankle linear velocity. This clearly demonstrated the phenomena of distal segments of a lever travelling faster than the proximal ones. It also provided quantitative evidence for the notion of the thigh initiating the kicking action, then slowing and allowing lower leg extension to dominate until the leg straightens (after contact); then a period of deceleration that has been otherwise called the follow through.

Film observation showed some medial rotation of the kicking leg during all trials. No data was available as to the extent or duration of this rotation which was considered to initiate at the hip (17). In anatomical terms, the lower limb medial rotators are much stronger and more mechanically efficient in terms of tendon alignment than the lateral rotators. Hip joint structure and the strong ilio-femoral ligament minimizes lateral rotation. Filming in the frontal plane is recommended for further analysis of this parameter.

Path of the Subject's Center of Gravity

The summation of all forces of a body are expressed via the center of gravity of that body. The graphical representations of the path of the subject's center of gravity are presented in Figures 12 to 15.

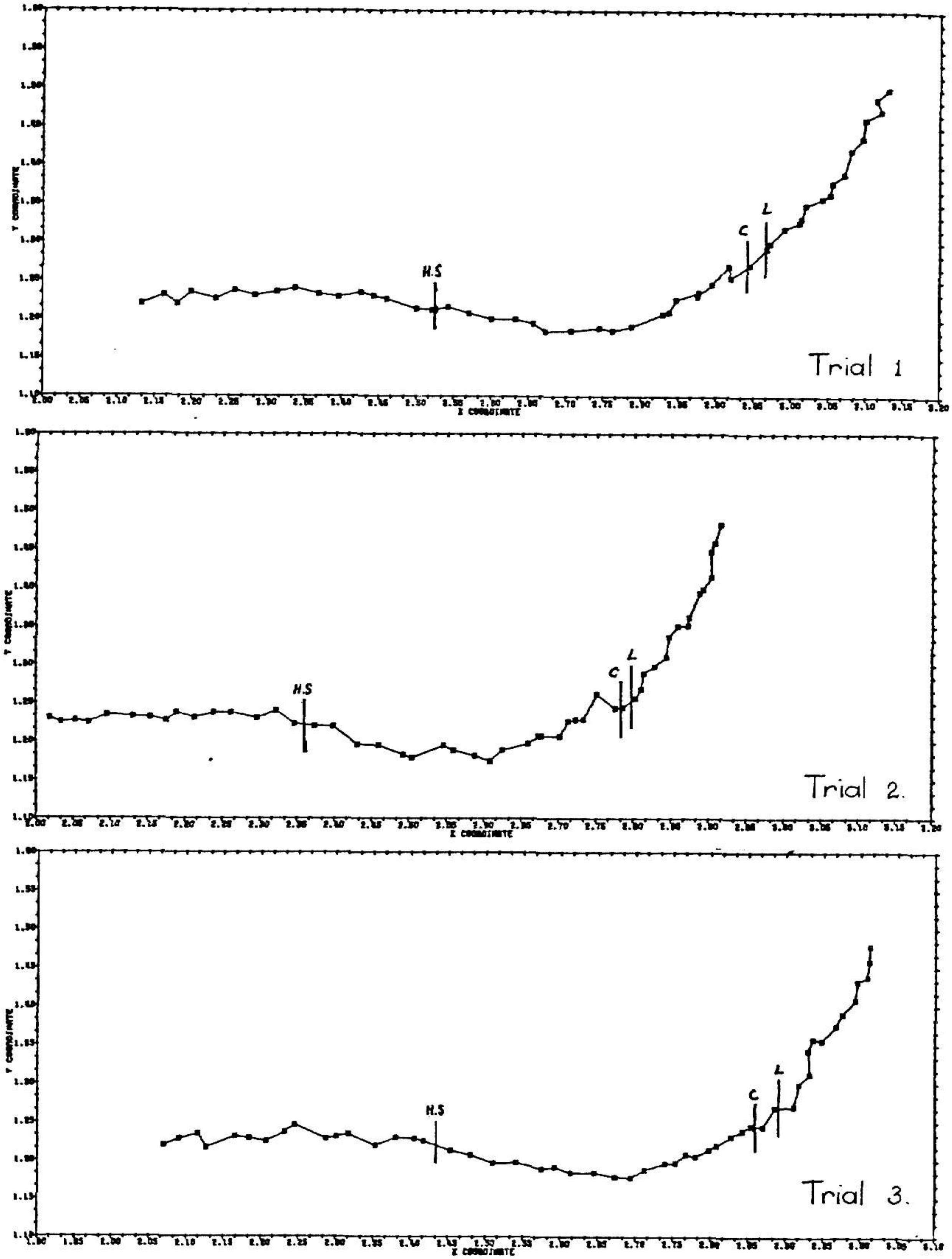


Figure 12

Path of Subject's Center of Gravity for Trials 1-3

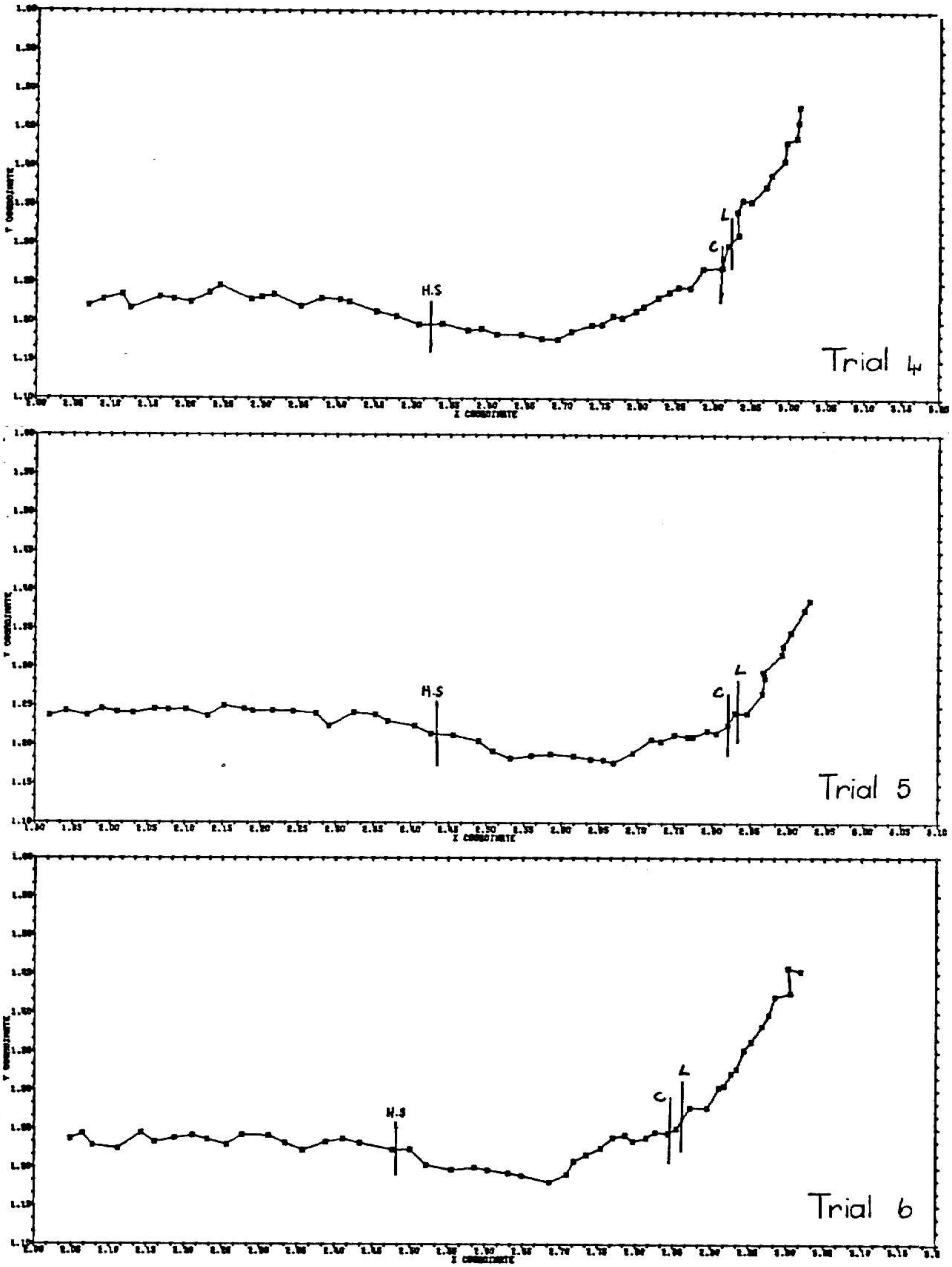


Figure 13

Path of Subject's Center of Gravity for Trials 4-6

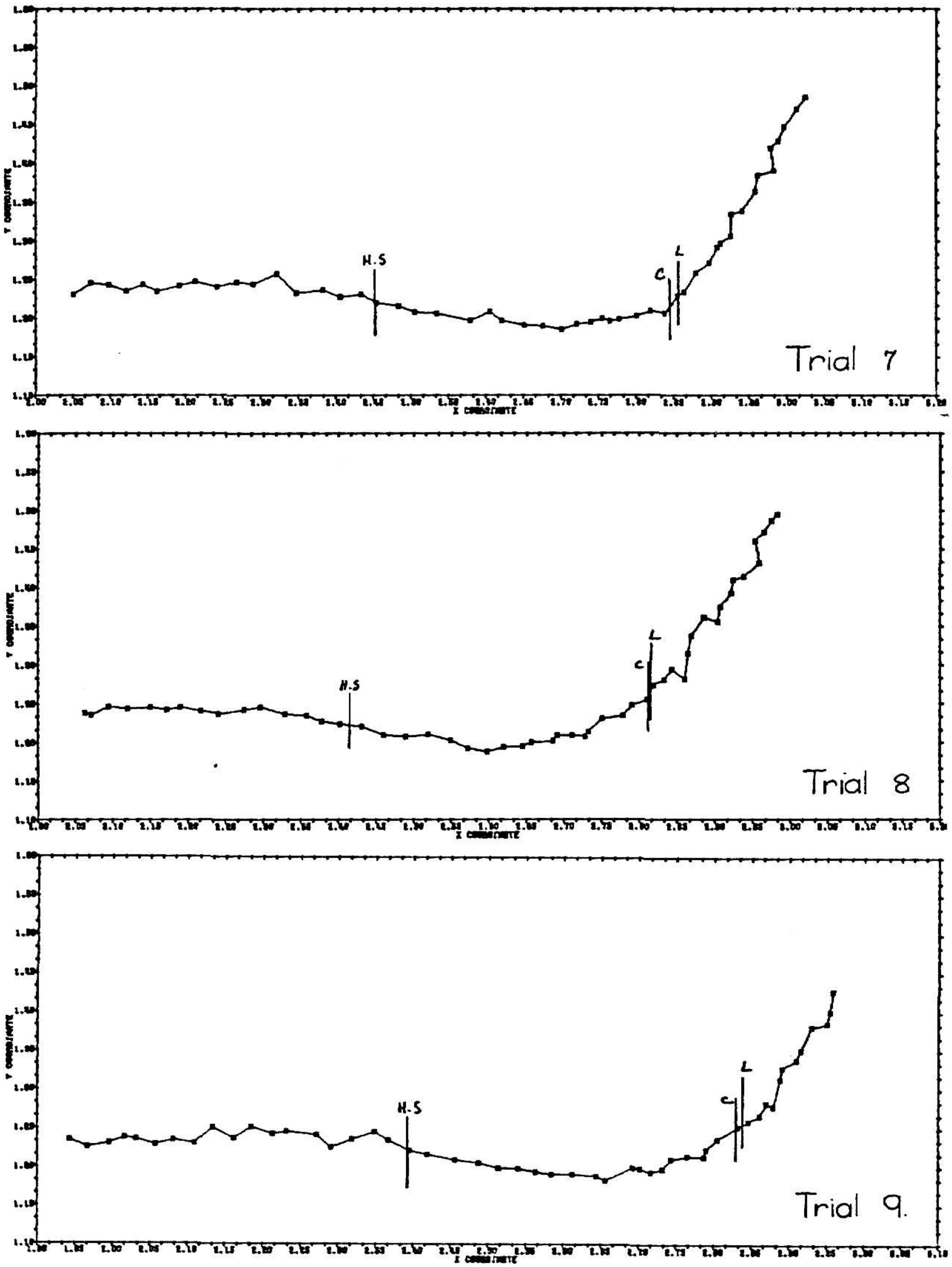
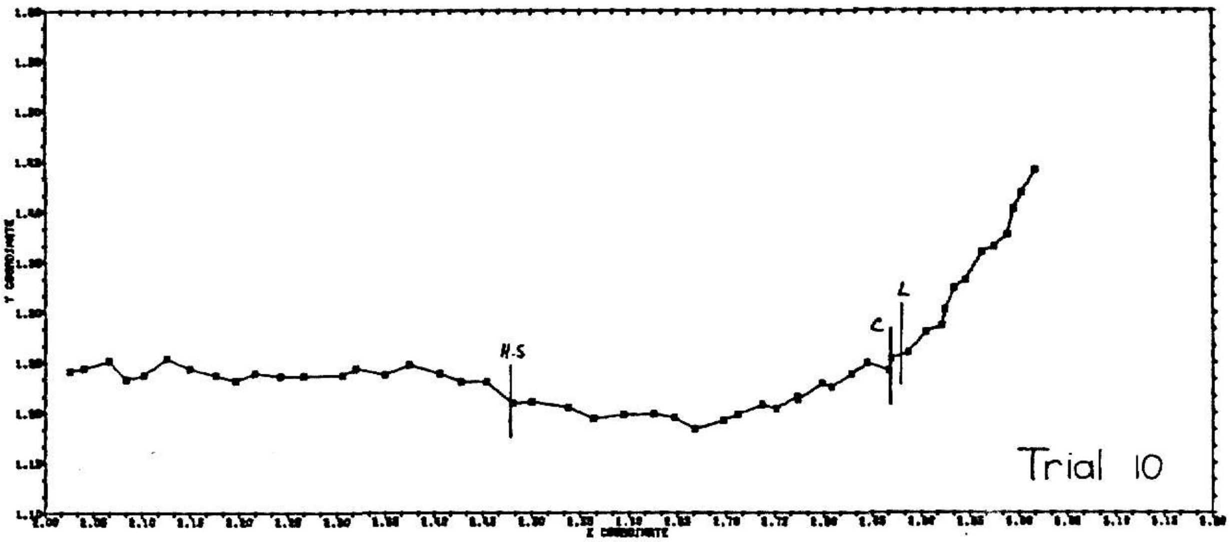
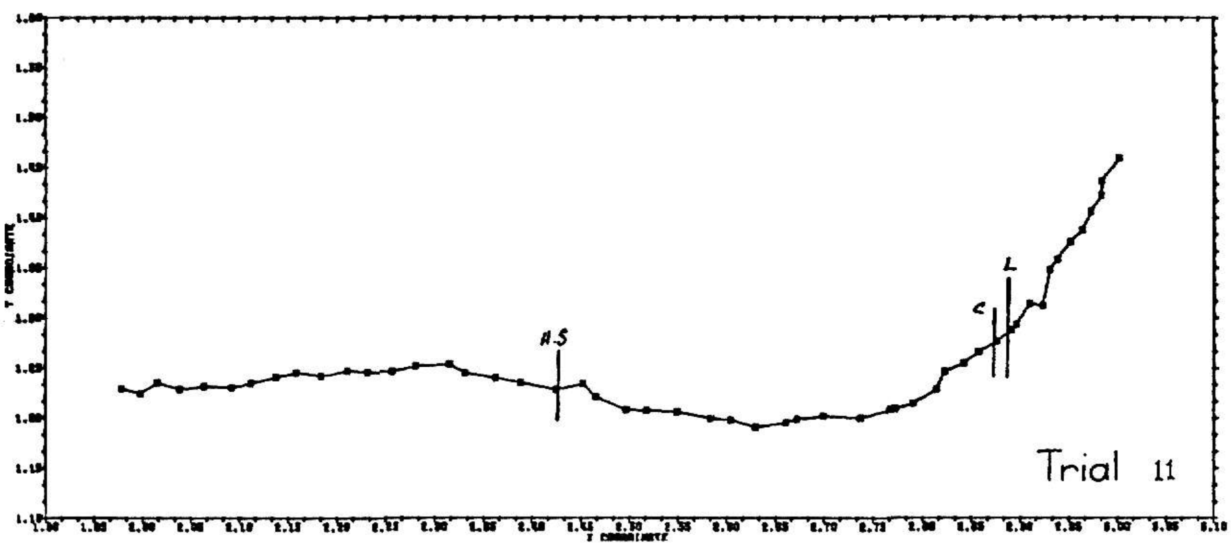


Figure 14

Path of Subject's Center of Gravity for Trials 7-9





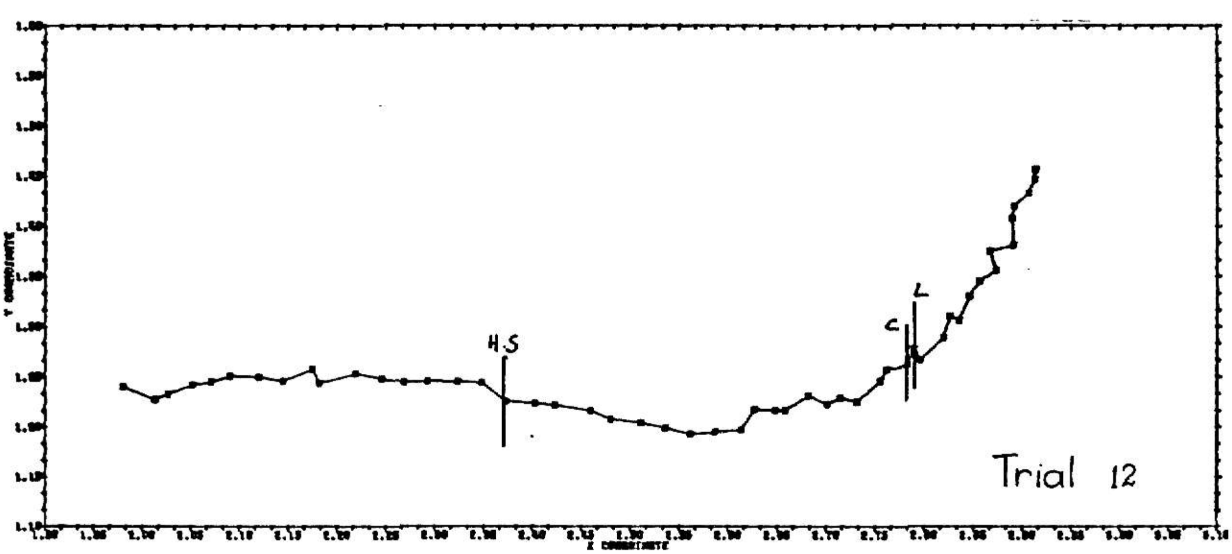


Figure 15

Path of Subject's Center of Gravity for Trials 10-12

To identify specific events during the kick, the following abbreviations were used: heel strike H.S., contact C, and launch L. Graphs for trials 3, 5, 9, 11 and 12 have a different abscissa. They have an origin of 1.90 seconds but the length and increments of the axis are the same as other trial graphs.

Each graph displayed a similar trend in that there was a period during the kick where the body center of gravity was depressed. This occurred prior to contact with the ball. At contact the subject's center of gravity was on average 1.31 meters from the ground. This represents almost 70% of the subjects standing height. Center of gravity height at contact information for all trials is listed in Table 31.

Table 31

Center of Gravity Height at Contact

Trial Number	Height, meters*
1	1.32
2	1.31
3	1.31
4	1.33
5	1.29
6	1.31
7	1.29
8	1.32
9	1.31
10	1.31
11	1.33
12	1.32
$\bar{x}$	1.31
SD	.01

*Y axis figure multiplied by 1.05 (the image to life size multiplier).

The steepest rise in the center of gravity occurred after contact. This was to be expected as the momentum generated by the kicker's leg was sufficient to lift him from the ground.

There was greater disparity in the timing of each of the specific events noted on the graphs. Table 32 lists these disparities.

Table 32

Specific Event Timing

Trial Number	Heel Strike, secs	Contact, secs	Launch, secs
1	0.124	0.274	0.282
2	0.120	0.282	0.288
3	0.126	0.286	0.296
4	0.150	0.308	0.316
5	0.172	0.324	0.332
6	0.140	0.286	0.294
7	0.130	0.278	0.286
8	0.118	0.266	0.272
9	0.144	0.306	0.312
10	0.152	0.308	0.314
11	0.148	0.306	0.314
12	0.130	0.284	0.292
$\bar{x}$	0.138	0.292	0.299
SD	0.02	0.03	0.02

Observation of the film did not reveal such disparity. The subject appeared to be very uniform in the gross action of kicking. Analysis of the film has shown that despite this apparent visual uniformity there were many differences in each trial.

Support Foot Lift

In all kicks the subject's momentum was sufficient to lift him off the ground. This occurred in the follow through phase. From the time of the ball launch to this happening was an average 0.13 seconds. The complete kick time analysis is in Appendix L.

As well as a period of both feet off the ground, the subject also travelled forward. This amount of travel was not measured but estimated after many viewings of the film to be approximately 0.3 meters.

There was much conjecture in the literature over whether the support leg should remain in contact with the ground or not. Hager (31) was the only author to recommend support foot lift, but only after ball contact. Others (28, 43, 57, 58) maintained that by having the support leg remain on the ground better balance and more power was generated in the kick.

It appeared that the subject in this study had adopted the practice of complete body lift in the follow through and that this was his personal preference. It would have been interesting to have coached the subject not to do this and to observe any change in the distance achieved in the punt kick.

What was important in this study was that all the follow through action, including the attitude of the support foot, was, in relative terms, long after the ball had left the kicker's foot. It may be possible to kick as far, or further, with a much reduced follow through which would in turn reduce the momentum of the swinging kick and perhaps eliminate totally the support foot lift.

The kicker's weight was supported and balanced on the left leg.

Film observation showed that the upper body and especially the arms made appropriate adjustments to maintain balance and equilibrium throughout the kicking action; see Figures 9 to 11. In all trials the left arm was raised noticeably in the early part of the kick. Both arms were extended laterally in the follow through phase. The subject repeatedly clenched his fists during this phase. The reason for this was not established.

SUMMARY OF BIOMECHANICAL PARAMETERS

The results of this aspect of the study are summarized in Appendix M. Of major importance were the following:

1. At the 0.05 level of significance there were no significant correlations. This suggested the possibility of the sample size being too small (N = 12), or there being too much error in the data collection, or that a number of the selected variables in harmony may correlate to a greater extent with the criterion variable of distance. Alternatively, it suggested that the variables selected were not important and that other factors may be present that contribute to gaining distance in the kick.

2. The approach to the kick seemed to be dominated by personal preference. Within the approach, the exaggerated second step with the left leg may enable greater right hip rotation and cause the right leg to be swung through a greater arc. A two, three or four step approach will be dominated by the ability of the center to snap the ball, and the ability of the kicker to execute the kick in 2 seconds or less (5, 8).

3. Ball release from the hands is considered important in

the popular coaching literature (5, 8, 28, 31, 35, 44, 46, 64). In this study the correlation against distance for the path of the ball at heel strike was $r = 0.55$ ($p \leq 0.07$) and the horizontal ball velocity at heel strike was $r = 0.53$ ($p \leq 0.08$). Both of these variables ensued from the ball release. They were the closest to significance of all of the 54 variables tested. The range of degrees for the ball angle at heel strike was only eight. This suggested reasonable consistency on the part of the kicker. It also suggested that only a few degrees difference here may be responsible for poor contact with the foot and subsequently less than optimum distance achieved. This aspect warrants further investigation.

4. Contact time between foot and ball ranged from 0.006 to 0.010 seconds. This was less than previously reported in the literature (3, 47). It appeared that proper ball-foot contact controlled the type of flight and the transfer of energy from foot to ball. The resultant ball flight was easy to monitor (Appendix D) but the initiation of it was impossible to see without the aid of high speed film.

5. Ball angle at contact varied from -6 to 25 degrees as evidenced in Figures 9 to 11. With only two exceptions, the front of the ball was tilted downward at contact. The best kick angle was five degrees, while the worst was 10 degrees. Obviously other factors influenced the resultant discrepancy in their distances.

6. Ball height from the ground at contact was reasonably uniform. The mean height was 0.38 meters and ranged from 0.36 to 0.42 meters. This variable had an r of -0.43, which tended to suggest that the lower the height from the ground, within the found or other optimum limits, the greater the distance attained. The kick of 61 meters was

initiated 0.36 meters from the ground. A larger number of trials may cast better light on this kicking parameter.

7. Foot linear velocity at contact ranged from 19.8 to 28.9 meters per second, with a mean of 25.7 m/s. An r of -0.12 suggested that, despite popular support, this variable had little relationship with distance. This finding confirmed that of Alexander and Holt (3).

8. Ball launch angle, presumed to optimize distance at 45 degrees, ranged from 39 to 59 degress, with a mean of 50 degrees. The negative correlation of -0.35 tended to suggest that the closer this launch angle can be to the optimum of 45 degrees the greater chance of maximum distance in the kick.

9. Plantar flexion of the foot was in evidence at contact in all trials. It was not established whether this flexion was maximal or not. Many authors referred to this as being 'the ankle locked'. What was also evident was the ball was struck higher up on the foot than the area generally designated as the instep. The exception to this was the poorest kick in terms of distance. It was struck much lower down the foot (Figure 11).

10. The study revealed that the punt kick was an extremely fast action. Ignoring the approach, the total time from release from the hands to launch averaged 0.3 of a second. Taking into account the time the kicker spent rotating the ball while motionless, and the kick time plus the time from the launch to the support foot lifting off the ground, the kick time amounted to 0.57 seconds. In the game situation it would appear that the slowest parts of punting are catching the snapped ball and taking the necessary steps to get the kick underway.

SPECIFIC FACTORS ASSOCIATED WITH SUPERIOR PERFORMANCE

Trial number 6 resulted in a 61 meter kick; trial 10 only 44 meters. It was assumed that the former was mechanically more efficient, so an attempt was made to contrast certain parameters associated with both kicks. Table 33 lists these parameter contrasts.

Table 33

Trial 6 and 10 Parameter Contrasts

Parameter	Trial 6 (good)	Trial 10 (poor)
Launch Angle, degrees	48	56
Hang Time, seconds	4	4
Linear Ball Velocity at Launch, m/s	24.3	28.6
Linear Ball Velocity in Flight, m/s	28.9	25.7
C of G Linear Velocity at Heel Strike, m/s	5.1	4.2
C of G Linear Velocity at Contact, m/s	1.9	2.2
C of G Linear Velocity at Launch, m/s	2.9	2.4
Distance ball dropped, m	0.61	0.57
Ball Height from ground at Contact, m	0.36	0.39
Ball Vector Angle at Heel Plant, degrees	46	42
Ball Vector Angle at Flight, degrees	46	49
Ball Angle to Horizontal at Heel Strike, degrees	11	19
Ball Angle to Horizontal at Contact, degrees	5	10
Ball Angle to Horizontal at Launch, degrees	4	9
Ball Angle to Horizontal In Flight, degrees	0	19
Horizontal Ball Velocity at Contact, m/s	2.8	3.1
Linear Ball Velocity at Contact, m/s	4.0	4.2
Rt. Toe Linear Velocity at Contact, m/s	25.3	26.3
Rt. Toe Linear Velocity at Launch, m/s	20.2	17.7
Rt. Toe Vertical Velocity at Contact, m/s	14.9	18.3
Rt. Toe Peak Linear Velocity, m/s	27.3	31.7
Ball Free Fall, secs	0.286	0.308
Contact Time, secs	0.008	0.006
Peak Knee Linear Velocity, m/s	11.69	13.78

From Table 33 the following was noted:

1. The launch angle was much higher in trial 10. The overall results tended to show that close to 45 degrees was the optimum launch

angle. The right toe vertical velocity was greater at contact in trial 10 also. This may explain the difference in launch angles. In the game situation a slightly higher launch angle may help prevent a blocked kick. Approximately 50 degrees is suggested.

2. Linear ball velocities at launch differed. Trial 10 was the maximum figure recorded in the study. This came about as a result of an increased vertical velocity of the foot at contact (18.3 m/s compared to 14.9 m/s). However, this situation was reversed in flight. Trial 6 had 28.9 m/s linear ball velocity in flight while trial 10 had 25.7 m/s. It was assumed that the transfer of force was more effective in trial 6. Aerodynamic factors may have influenced the apparent loss of velocity in trial 10.

3. The ball was in contact a shorter time with the foot in trial 10. This may have been critical in the transfer of force. This, linked with an instep contact that was considered inferior (2, 3), and a higher launch angle, may explain the almost 18 meter difference in the kicks. Table 34 shows the percentage difference amongst selected variables.

Table 34

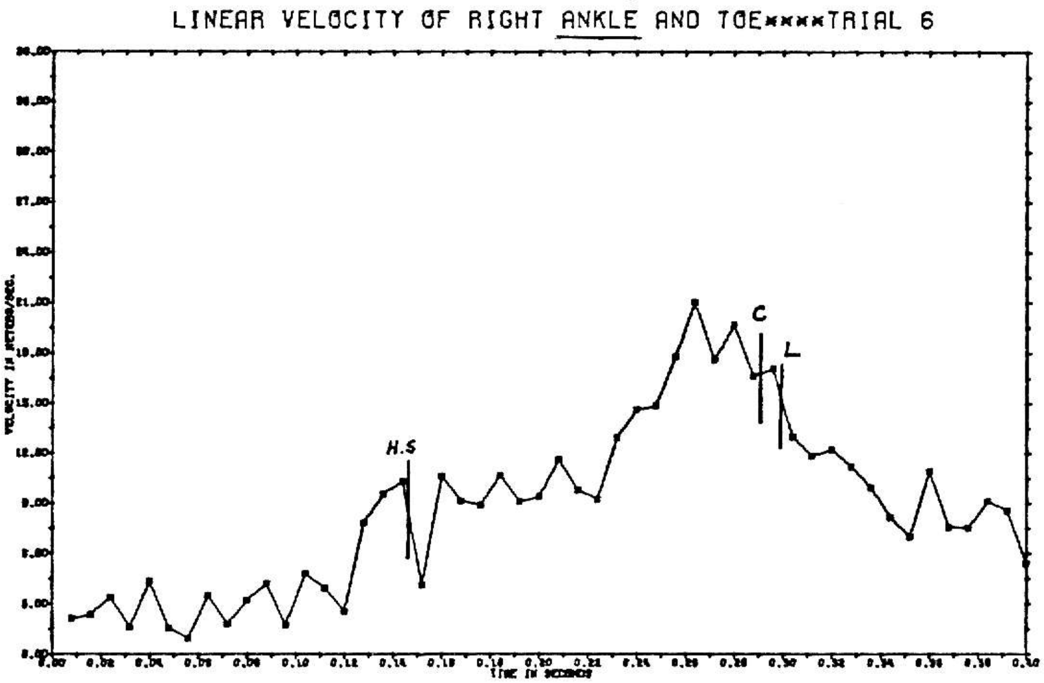
Selected Variable Percentage Differences

Variable	Superior Punt	Poor Punt	% Difference
Distance, m	61.2	43.9	28
Rt. Toe Linear Velocity at Contact, m/s	25.3	26.3	-3.8*
Rt. Toe Linear Velocity at Launch, m/s	20.2	17.7	12.4
Linear Velocity of Ball at Launch, m/s	24.3	28.6	-15
Linear Velocity of Ball In Flight, m/s	28.9	25.7	11
Contact Time, secs	.008	.006	25

*This was previously considered the most critical aspect (5, 10, 13, 47).

4. There was a loss in linear velocity of the right toe from contact to launch in both trials. The loss was greater in trial 10 (8.6 m/s compared to 5.1 m/s in trial 6). This difference in linear velocity was calculated for all trials (Appendix M) and the following data resulted: mean difference 5.84 m/s, standard devation 2.58 m/s, correlated -0.35 with distance (not significant). More research is needed to determine what is effective force transfer as indicated by velocity loss of the striking implement.

5. The data revealed that trial 10 may have been inferior due to poor timing in the kick. Linear velocities of the right ankle and toe are presented graphically in Figures 16 and 17.



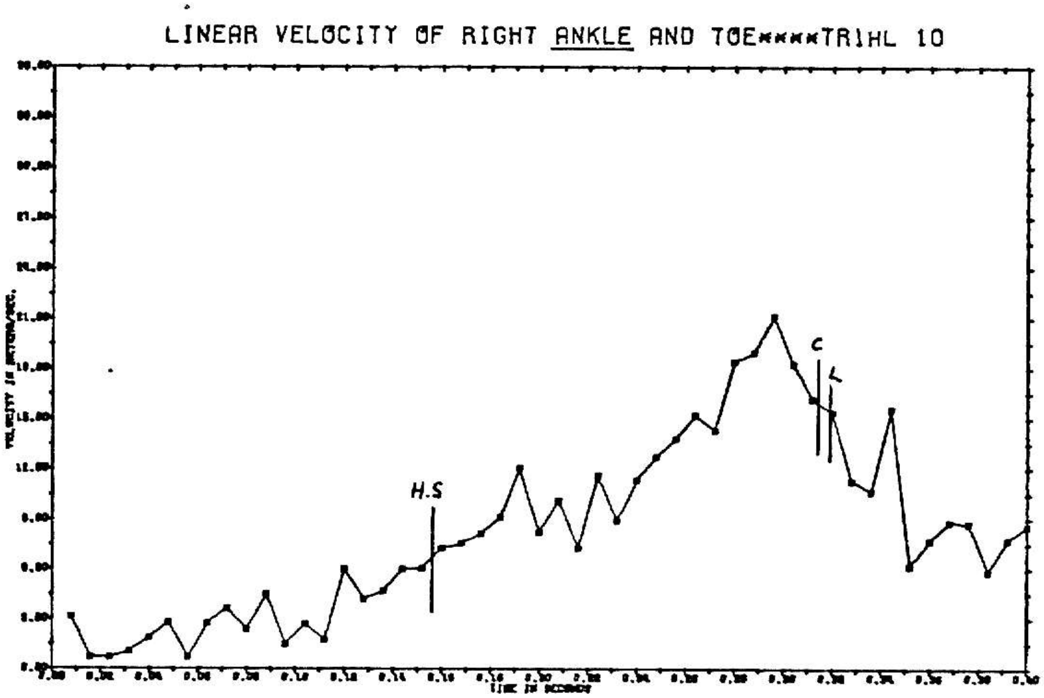
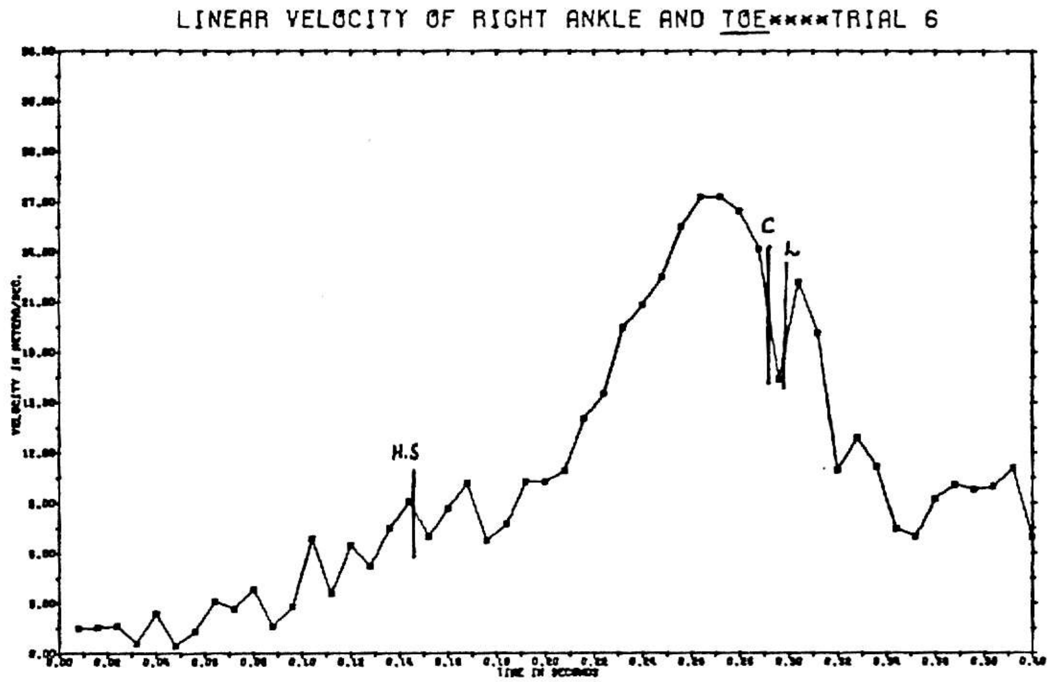


Figure 16

Linear Velocities of Right Ankle for Trials 6 and 10



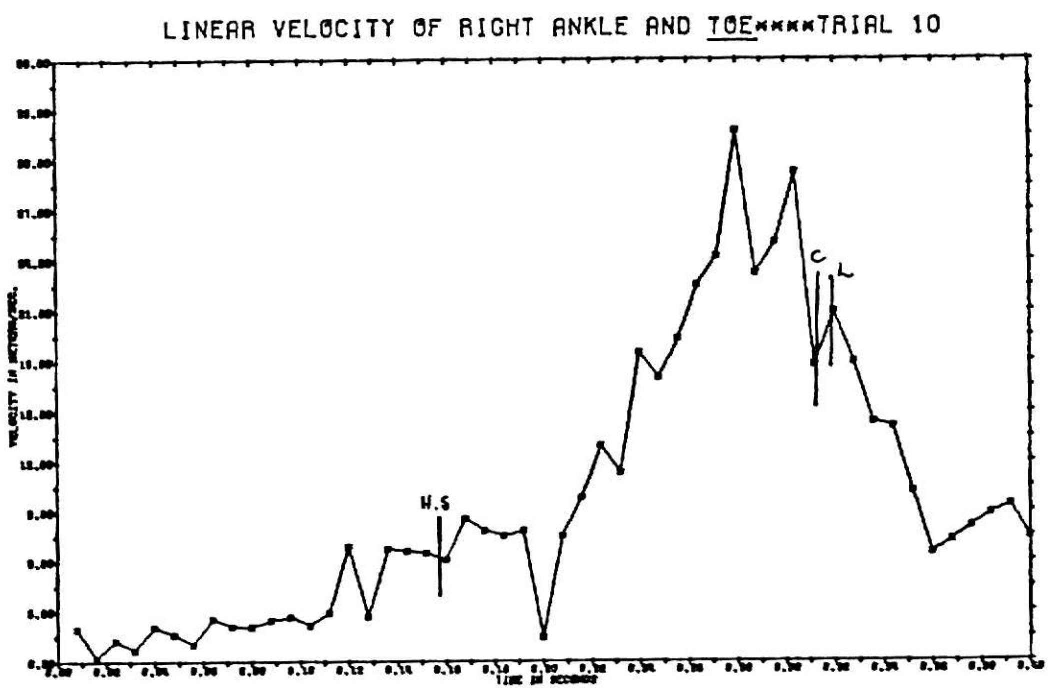


Figure 17

Linear Velocities of Right Toe for Trials 6 and 10

Peak linear velocity for the right ankle was the same for both trials. It was reached 0.032 seconds before contact in trial 6 and 0.024 seconds before contact in trial 10. In trial 6 there was not the slowing up evidenced in trial 10 between contact and launch. In both trials the ankle velocity revealed a similar slowing effect after contact, with both then displaying a rather erratic speeding up. In trial 6 this occurred 0.056 seconds after launch, while only 0.024 seconds after launch in trial 10.

Peak linear velocity for the right toe showed a contrasting pattern. There was a reasonably consistent pattern of acceleration in trial 6, with peak velocity being reached 0.016 seconds before contact. Trial 10 displayed a more erratic pattern. Two peaks in linear velocity occurred. The first peak was 0.040 seconds before contact and the second 0.016 seconds before. In trial 6 there was an immediate speeding up after launch, while in trial 10 the right toe velocity fell rapidly immediately after launch.

SPECIFIC FACTORS SUMMARY

Although there was a wide amount of variance in the distance achieved between the two trials there was not a great amount of variance in the basic mechanics of the two punts. For instance, Table 21 showed very similar body angles at contact. This implied that in some factors a small amount of variance may be critical. Included in these factors may be the following: contact time, angle of the ball at contact, and foot to ball contact. The contact time difference of 0.002 seconds may be critical in conjunction with the other two factors. Alone it appeared doubtful as contact time showed only a relationship of r = 0.34

with distance. Small variation in the angle of the ball at contact and the foot to ball contact may also be a critical factor. Figures 10 and 11 show this difference in contact between the two trials.

The small difference between the right toe linear velocity at contact (1 m/s) showed clearly that the speed of the foot was not a factor associated with superior performance. This example, though isolated, tended to confirm the overall impression from the study that ball-foot contact is a paramount factor in effective punt kicking. Setting up the ideal ball-foot contact also involved the releasing of the ball from the hands. Using the football laces as a guide, it was obvious from Figures 9, 10 and 11 that variation existed in each trial. The ball rotation about its short axis may have been critical in establishing an optimum angle of the ball across the foot. In essence, the period from ball release to contact was critical, and it was at this time that the kicker had least control over the ball.

Chapter 5

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

A summary of this study is presented here. The summary includes the statement of the problem, the purpose and the procedures followed. The main findings are then presented, conclusions are drawn from these and the chapter concludes with recommendations for further study.

SUMMARY

The Problem

Biomechanical parameters of punt kicking have not been fully understood or documented. The problems involved in this investigation were two-fold:

a) to establish a list of biomechanical parameters of punt kicking; and

b) to isolate from these parameters specific factors associated with superior performance.

Purpose of the Study

By the use of cinematographical analysis, biomechanical parameters of punt kicking were to be established. From these parameters associated with the performance of an expert kicker some guidelines were to be established as to what are the most important factors in successful punt kicking.

Procedures

A kicker from a team in the Big 8 Football Conference was filmed at 500 fps using a Red Lakes Laboratory Locam Camera. Twelve trials were analyzed with a Vanguard Motion Analyzer, a digitizer linked with an on-line paper tape punch and automated teletype printer. The film data was further reduced by computer using the 'Wildcat' biomechanics Fortran program. This program generated information concerning the subject center of gravity and its velocity in three planes, as well as 3 plane velocities for all limb segments. Fifty-one frames per trial were analyzed having selected each fourth frame for analysis.

FINDINGS

The following is a summary of the findings in this investigation:

1. Despite a seemingly consistent overall kicking pattern there was a great disparity in the distance achieved with each kick.

2. The subject spent a proportionately long time (10% of the total kick time) turning the ball around to arrive at a laces up position prior to any forward movement after the catch from the center snap. At contact this laces up attitude of the ball had changed.

3. The subject was still able to execute the punt kick within the arbitrary time confines of a game situation.

4. The punt kick is an extremely fast action in which the ball is in contact with the foot less than 0.01 seconds.

5. The contact area was above the instep, near the anterior, distal aspect of the ankle. Contact lower down the foot may have contributed to poor performance by reason of a loss of energy transference.

6. No one single variable correlated significantly ($p \leq 0.05$) with distance. It was suggested that the number of trials need be increased, or the measurement error be reduced, or some combination of existing variables be made, or that any combination of these suggestions may show greater relationship and significance and hence guide the future researcher's investigations.

7. Foot speed was *not* the critical factor previously thought in punting. In fact this study showed that the average foot speed at contact (25.7 m/s) was greater than that of the exceptional kick (25.3 m/s).

8. Peak right toe velocity was reached prior to contact.

9. The ball was struck consistently about 0.38 meters from the ground. There was obviously some compromise between this height and the proximity to peak toe velocity. The exact optimums for each of these factors were not established.

10. The kicking leg was not straight at contact; the mean angle was 170 degrees.

11. From release from the hands to the point of contact, the ball travels a curved path. It does not simply drop straight down. In fact, the horizontal ball velocity at contact was greater than that of the subject's center of gravity. This suggested that the ball was propelled out and down towards the foot.

12. In all trials it was obvious that the ball was angled across the foot at contact. No exact data was available because of uni-planar filming. According to Alexander and Holt (3) this angle is important because it prevents premature contact with the ends of the ball and enables the kicker to contact the "belly" of the football.

13. Appendix M provided a summary of the biomechanical parameters considered important in this study. Mean, range and standard deviation as well as correlation data were presented.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn from the data:

1. Despite a seemingly large number of biomechanical parameters involved in punting, there was no single parameter that correlated significantly with the criterion variable of distance ($p \leq 0.05$). This suggested that more trials were needed, or other parameters be established and tested against this criterion. The development of an optimum model for punt kicking still awaits further research.

2. The aspiring kicker, or coach, should treat with caution much of the existing kicking literature. Greater concern may need be made for individual differences such as body size, leg strength, flexibility and even personal preference in the development of expert punters.

RECOMMENDATIONS

The following recommendations are presented for further research. They are based on the findings and conclusions of this study.

1. A large number of trials for one expert punter should be filmed. Subsequent analysis and resulting parameters may then have some statistical credence, and from such data an optimum model may be established. Such a model may provide an excellent teaching and coaching tool.

2. Tri-axial cinematography may provide further information

about punting. Unfortunately there is not a large data bank within biomechanics that deals with three dimensional mechanics. One more camera in the frontal plane would provide information on the angle of the ball across the foot, the extent, if any, of hip or knee rotation, where the support foot is planted relative to the mid-line of the body, and the upper body angle in the sagittal plane.

3. More research will be needed with ball aerodynamics. If air resistance factors reduce the potential distance of a punt kick by half (19), then some information should be gathered on the effect of spin on the ball, whether or not it precesses and the effect of the laces and the seams and the general texture of the football. A wind tunnel experiment may assist in this regard.

4. Unresolved factors from this study should be further investigated. These included the following: (a) the effect of keeping the support foot on the ground during the follow through; (b) determining exactly what part of the foot and/or ankle joint contacts the ball (coaches may try chalking or dyeing the ball to gain some information on this); (c) determining exactly what creates a spiral - the shape of the ball, the nature of the contact or what?; (d) determining why the ball velocity increases after launch.

5. Every effort should be made to simulate the game situation when filming. It appears that the oncoming defensive rush has an effect on a kicker. The kicker in this study was not able to consistently replicate the superior distance acheived in this experimental setting in the conference games.

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APPENDICES

APPENDIX A

SUBJECT ANTHROPOMETRIC DATA

Age: 22 years

Weight: 86.4 kg (190 lbs)

Height: 1.8 m (6'0")

Limb Segment Lengths:	Right Thigh	377 mm (14.8")
	Right Lower Leg	444 mm (17.5")
	Right Upper Arm	291 mm (11.5")
	Right Lower Arm	268 mm (10.5")
	Right Foot	264 mm (10.4")

APPENDIX B

JOINT CENTERS MARKED

Joint	Location
Shoulder	Lateral head of humerus
Elbow	Lateral epicondyle of humerus
Wrist	Ulnar styloid process
Hip	Greater trochanter of femur
Knee	Lateral epicondyle of femur
Ankle	Lateral malleolus

APPENDIX C

NINETEEN POINTS FOR SEGMENTAL ANALYSIS

Head and Neck Segment: Tragus of the ear

Trunk Segment: Top of sternum to the pubic bone (crotch)

Top of Sternum: Notch of the manubrium

Arms:*

Shoulder Joint: Lateral head of the humerus

Elbow Joint: Lateral epicondyle of the humerus

Wrist Joint: Ulnar styloid process

Hand Segment: Furthest extension of the hand

Legs:*

Hip Joint: Greater trochanter of the femur

Knee Joint: Lateral epicondyle of the femur

Ankle Joint: The malleolus of the ankle joint

Foot Segment: Furthest extension of the foot

*Readings were taken for both the right and left sides

APPENDIX D

SUBJECT DATA SHEET

Name: W. S.

Date: 26 September 1976

Age: 22 years

Height: 1.8 m (6.0')

Weight: 86.4 kg (190 lbs)

Skill: Punt Kick

Trials	Time for Kick*	Hang Time**	Distance***	Comment
1	1.3 secs	4.2 secs	51 m (56 yds)	Low snap
2	1.5 secs	4.3 secs	55 m (60 yds)	Good
3	1.5 secs	4.2 secs	52 m (57 yds)	Good
4	1.4 secs	4.3 secs	57 m (62 yds)	Slightly low
5	1.5 secs	4.2 secs	46 m (50 yds)	--
6	1.6 secs	4.0 secs	61 m (67 yds)	Good
7	1.5 secs	4.0 secs	52 m (57 yds)	--
8	1.5 secs	3.5 secs	51 m (56 yds)	To the right
9	1.4 secs	3.6 secs	47 m (52 yds)	--
10	1.5 secs	4.0 secs	44 m (48 yds)	--
11	1.4 secs	3.6 secs	52 m (57 yds)	To the right
12	1.5 secs	4.3 secs	56 m (61 yds)	Wide right

*Mean 1.46 secs

**Mean 4.0 secs

***Mean 52 m (57 yds)

APPENDIX E

CINEMATOGRAPHICAL RECORD SHEET

Reel Number: 1

Activity: Mechanical Analysis

Skill Filmed: Punt Kick

Date Filmed: 26 September 1976

Equipment Placement:

1. Camera

    a. model: Locam 51-0002

    b. distance from subject: 18.3 m (60')

    c. lens height: 1.42 m (4.6')

    d. f/setting: f 8

    e. shutter factor: open

    f. frame rate: 500 fps

    g. mode of operation: electric 115V

    h. film type: 7277 Kodak Tri-X (400 ASA)

    i. lens: 25 mm

2. Timing Device

    a. model: black face one-hundredth of a second

    b. distance: 8 m (27')

    c. height: ground level

3. Lighting

    a. type: natural (sunny conditions)

4. Other equipment

    a. subject & trial identification numbers

    b. tripod

c. power leads

d. light meter

e. spirit level

APPENDIX F

INFORMED CONSENT

I understand that the purpose of this study is to learn more about the biomechanics of kicking, and in particular the punt kick.

I confirm that my participation as a subject is entirely voluntary. No coercion of any kind has been used to obtain my cooperation.

I understand that I may withdraw my consent and terminate my participation at any time during the investigation.

I have been informed of the procedures that will be used in the study and understand what will be required of me as a subject.

I understand that all of my responses, written or oral, will remain completely anonymous.

I wish to give my cooperation as a subject.

Signed:

Date:

APPENDIX G

Table 14

Distance Ball Drops

Trial Number	Distance (meters)	
1	0.56	(1.84 feet)
2	0.60	(1.97 feet)
3	0.58	(1.90 feet)
4	0.50	(1.64 feet)
5	0.57	(1.87 feet)
6	0.61	(2.00 feet)
7	0.58	(1.90 feet)
8	0.53	(1.74 feet)
9	0.62	(2.03 feet)
10	0.57	(1.87 feet)
11	0.59	(1.94 feet)
12	0.61	(2.00 feet)
$\bar{x}$	0.57	
SD	0.03	

APPENDIX H

Table 15

Ball Angle to Horizontal at Heel Strike

Trial Number	Degrees*
1	22
2	22
3	11
4	26
5	13
6	11
7	25
8	16
9	20
10	19
11	30
12	8
$\bar{x}$	18.6
SD	6.9

*Relative to the horizontal and based on the end coordinates of the football.

APPENDIX I

Table 16

Vector Velocity Angle of Football at Heel Strike

Trial Number	Degrees
1	42
2	42
3	47
4	44
5	42
6	46
7	42
8	39
9	40
10	42
11	42
12	44
$\bar{x}$	42.7
SD	2.6

APPENDIX J

Table 25

Right Ankle Joint Linear Velocity Just Prior to, or at Contact

Trial Number	Linear, m/s
1	18.7
2	18.2
3	17.2
4	19.4
5	19.1
6	19.6
7	18.9
8	19.3
9	19.8
10	18.2
11	17.4
12	16.2
$\bar{x}$	18.5
SD	1.0

APPENDIX K

Table 35

Ball Snap Conditions

Trial Number	Comment	Time From Catch to First Motion of Rt. Thigh Forwards, secs
1	Very low snap	.146
2	Head high snap	.138
3	Chest level: upper body movement preceeded thigh movement	.240
4	Low snap	.138
5	Face level	.108
6	Knee high snap	.200
7	Waist high: early trunk movement	.070
8	Chest level	.112
9	Head high	.128
10	Mid-chest: movement started prior to laces-up ball position	.134
11	Chest level	.148
12	Waist level: Rt. hip movement prior to laces-up ball position	.166
$\bar{x}$		.144

APPENDIX L

Table 36

Kick Time Analysis, seconds

Trial #	Time 'Motionless' Rotating Ball	Free Fall of Ball	Ball Release from Hands to Support Foot Heel Strike	Support Foot Heel Strike to Contact	Contact	Launch to Support Foot Lift Off
1	.146	.274	.124	.150	.008	.132
2	.138	.282	.120	.162	.006	.126
3	.240	.286	.126	.160	.010	.126
4	.138	.308	.150	.158	.008	.130
5	.108	.322	.172	.152	.008	.124
6	.200	.286	.140	.146	.008	.126
7	.070	.278	.130	.148	.008	.136
8	.112	.266	.118	.148	.006	.132
9	.128	.302	.144	.162	.006	.134
10	.134	.308	.152	.156	.006	.130
11	.148	.306	.148	.158	.008	.134
12	.166	.284	.130	.154	.008	.132
$\bar{x}$	.14	.292	.138	.154	.0075	.130

APPENDIX M

Table 37

Total Parameter Statistics

Trial # Units		Distance meters	Predicted Range meters	Launch Angle degrees	Linear Ball Velocity at Launch m/s	Hang Time m/s	C of G Linear Velocity at Heel Strike m/s	C of G Linear Velocity at Contact m/s	C of G Linear Velocity at Launch m/s
6		61.2	42.3	48	24.3	4.0	5.1	1.9	2.9
4		56.7	42.1	48	24.2	4.3	4.0	2.3	2.8
12		55.7	41.3	52	27.1	4.3	3.9	2.7	2.1
2		54.8	39.2	55	26.1	4.3	3.7	1.4	2.3
3		52.1	40.5	51	20.7	4.2	3.4	1.9	3.4
7		52.1	42.5	39	21.8	4.0	3.1	2.5	2.5
11		52.1	44.9	47	26.2	3.6	4.6	2.9	2.4
1		51.6	42.8	47	21.2	4.2	2.8	3.9	4.1
8		51.2	42.8	49	27.0	3.5	3.5	2.7	2.6
9		47.5	38.1	59	26.2	3.6	3.4	4.1	3.6
5		46.2	43.4	50	23.9	4.2	3.3	2.4	2.2
10		43.9	31.2	56	28.6	4.0	4.2	2.2	2.4
$\bar{x}$	=	52.1	40.9	50.1	24.8	4.0	3.7	2.6	2.8
Range	=	43.9-61.2	38.1-44.9	39-59	20.7-28.6	3.5-4.3	2.8-4.6	1.9-4.1	2.1-4.1
SD	=	4.7	3.6	5.2	2.5	0.3	0.6	0.8	0.6
r distance, xi	=	1.00	0.48	-0.35	-0.21	0.27	0.44	-0.34	-0.01
Significance			$p < =.11$				$p < =.15$		

Table 37 (continued)

Trial # Units	C of G Velocity at Last Frame m/s	Distance Ball Drops meters	Ball Ht. from Grnd at Contact meters	Ball Vector Angle at Heel Strike degrees	Ball Vector Angle in Flight (at support foot lift) degrees	Ball Angle to Horizontal at Heel Strike degrees	Ball Angle to Horizontal at Contact degrees
6	2.2	.61	.36	46	46	11	5
4	3.1	.50	.38	44	50	26	12
12	1.3	.61	.36	44	52	8	2
2	3.3	.60	.39	42	52	22	18
3	2.6	.58	.39	47	53	11	-6
7	2.6	.58	.40	42	47	25	22
11	3.9	.59	.36	42	46	30	23
1	2.6	.56	.36	42	51	22	25
8	1.5	.53	.38	39	47	16	8
9	3.5	.62	.42	40	53	20	19
5	1.8	.57	.37	42	50	13	9
10	3.4	.57	.39	42	49	19	10
$\bar{x}$ =	2.65	.57	.38	42.7	49.7	18.6	12.3
Range =	1.3-3.9	.50-.62	.36-.42	39-47	46-53	8-30	-6 - 25
SD =	0.83	.03	.02	2.27	2.64	6.86	9.42
r distance, xi =	-0.21	0.04	-0.43	0.55	-0.20	-0.11	-0.17
Significance:			p <=.17	p <=.07			

Table 37 (Continued)

Trial # Units	Ball Angle to Horizontal at Launch degrees	Ball Angle to Horizontal at Support Foot Lift degrees	Relationship of C of G of Ball and C of G of Foot mm	Horizontal Ball Velocity at Contact m/s	Vertical Ball Velocity at Contact	Linear Ball Velocity at Contact
6	4	0	40.9	2.8	2.9	4.0
4	6	30	25.2	3.0	2.9	4.2
12	-10	-40	29.4	3.1	3.0	4.3
2	19	52	21.0	3.0	2.7	4.0
3	-5	32	59.0	2.7	2.9	3.9
7	19	34	17.8	3.2	2.9	4.3
11	17	-22	31.5	3.1	2.8	4.2
1	14	25	31.5	3.1	2.8	4.2
8	4	-32	39.9	3.4	2.7	4.3
9	7	-33	16.8	3.4	2.8	4.4
5	15	21	31.5	3.2	2.9	4.3
10	9	19	26.3	3.1	2.8	4.2
$\bar{x}$	= 9.00	7.12	30.90	3.10	2.84	4.19
Range	= -10 - 19	-40 - 52	16.8-59.0	2.7-3.4	2.7-3.0	3.9-4.4
SD	= 7.89	31.32	11.66	.21	0.09	0.15
r distance, xi =	-0.22	0.01	0.20	-0.53	0.28	-0.46
Significance:	$p \leq .48$			$p <= .08$		

Table 37 (Continued)

Trial # Units	Horizontal Ball Velocity at Launch m/s	Vertical Ball Velocity at Launch m/s	Horizontal Ball Velocity in Flight m/s	Vertical Ball Velocity in Flight m/s	Linear Ball Velocity in Flight m/s	Subject C of G X Coordinate at Heel Strike Vanguard Units
6	16.1	18.2	20.2	20.6	28.9	2.48
4	16.1	18.1	18.5	22.1	28.8	2.42
12	15.3	22.4	17.9	22.7	28.9	2.37
2	15.1	21.3	17.7	22.5	28.6	2.37
3	13.0	16.1	17.3	22.7	28.5	2.44
7	17.1	13.6	20.0	21.3	29.2	2.45
11	17.7	19.3	20.8	21.2	29.7	2.43
1	14.3	15.6	18.2	22.6	29.0	2.53
8	17.5	20.6	19.7	21.4	29.1	2.42
9	13.3	22.6	17.4	23.4	29.1	2.38
5	15.1	18.1	18.6	22.1	29.4	2.43
10	17.1	25.0	17.0	19.3	25.7	2.47
$\bar{x}$	= 15.6	19.2	18.6	21.8	28.7	2.43
Range	=13.0-17.7	13.6-25	17.0-20.8	19.3-23.4	24.7-29.7	2.37-2.53
SD	= 1.58	3.30	1.27	1.12	1.01	.04
r distance, xi=	0.06	-0.31	0.41	0.12	0.40	-0.04
Signifance:		p < =.33	p < =.19		p < =.20	

Table 37 (Continued)

Trial # Units	Subject C of G Y Coordinate at Heel Strike Vanguard Units	Subject C of G X Coordinate at Contact Vanguard Units	Subject C of G Y Coordinate at Contact Vanguard Units	Subject C of G X Coordinate at Launch Vanguard Units	Subject C of G Y Coordinate at Launch Vanguard Units	Subject C of G X Coordinate at Last Frame Vanguard Units	Subject C of G Y Coordinate at Last Frame Vanguard Units
6	1.21	2.85	1.22	2.86	1.26	3.02	1.45
4	1.22	2.84	1.26	2.85	1.27	2.95	1.43
12	1.23	2.78	1.26	2.79	1.27	2.91	1.46
2	1.22	2.79	1.24	2.80	1.25	2.92	1.48
3	1.22	2.86	1.24	2.89	1.26	3.01	1.48
7	1.22	2.86	1.22	2.87	1.24	3.02	1.48
11	1.23	2.88	1.28	2.89	1.29	3.00	1.46
1	1.21	2.94	1.27	2.97	1.29	3.13	1.50
8	1.22	2.81	1.25	2.81	1.26	2.98	1.49
9	1.22	2.83	1.25	2.84	1.25	2.96	1.43
5	1.21	2.82	1.23	2.83	1.24	2.93	1.39
10	1.21	2.87	1.25	2.89	1.26	3.02	1.44
$\bar{x}$	= 1.21	2.84	1.25	2.86	1.26	2.99	1.46
Range	=1.21-1.23	2.78-2.94	1.22-1.28	2.79-2.97	1.24-1.29	2.91-3.02	1.39-1.50
SD	= 0.007	0.04	0.018	0.04	0.016	0.06	0.03
r distance, xi	= 0.24	-0.16	-0.11	-0.17	0.24	-0.06	0.30
Significance:							

Table 37 (Continued)

Trial # Units	Rt. Toe Horizontal Velocity at Contact m/s	Rt. Toe Vertical Velocity at Contact m/s	Rt. Toe Linear Velocity at Contact m/s	Rt. Toe Horizontal Peak Velocity m/s	Rt. Toe Horizontal Velocity at Launch m/s	Rt. Toe Vertical Velocity at Launch m/s	Rt. Toe Linear Velocity at Launch m/s
6	21.6	14.9	25.3	27.2	13.1	14.2	20.2
4	20.7	15.4	26.2	31.1	13.0	19.5	22.9
12	18.6	18.0	26.3	27.2	10.4	18.8	21.5
2	21.8	19.0	28.9	30.7	12.1	15.6	19.7
3	19.2	16.3	25.6	27.8	13.1	18.0	19.1
7	20.9	17.3	23.0	27.5	13.9	18.3	19.1
11	13.1	14.8	19.8	27.5	13.1	14.8	19.8
1	21.5	17.3	27.6	32.8	12.5	15.5	19.8
8	19.3	15.7	24.9	27.0	12.3	12.4	17.5
9	19.4	19.6	27.6	28.9	14.5	15.0	20.9
5	21.8	16.0	27.5	28.9	10.7	17.6	20.7
10	18.9	18.3	26.3	31.6	13.5	11.4	17.7
$\bar{x}$	= 19.7	16.9	25.7	29.0	12.7	15.9	19.9
Range	= 13.1-21.8	14.8-19.6	19.8-28.9	27.2-32.8	10.4-14.5	11.4-19.5	17.5-22.9
SD	= 2.4	1.61	2.42	2.02	1.20	2.56	1.51
r distance, xi	= 0.15	-0.39	-0.12	-0.27	-0.12	0.34	0.41
Significance:		$p < =.20$					$p < =.18$

Table 37 (Continued)

Trial # Units	Rt. Toe Peak Vertical Velocity m/s	Rt. Toe Horizontal Velocity Last Frame m/s	Rt. Toe Vertical Velocity Last Frame m/s	Rt. Toe Linear Velocity Last Frame m/s	Rt. Toe Peak Linear Velocity m/s	Ball Free Fall secs	Ball Release to Support Foot Heel Strike secs
6	21.5	-1.1	6.8	6.9	27.3	.286	.140
4	27.6	-0.9	9.9	10.0	31.5	.308	.150
12	21.0	-3.0	7.6	8.2	27.8	.284	.130
2	9.1	-3.9	9.1	9.8	30.8	.282	.120
3	20.3	-2.8	6.8	7.4	29.8	.286	.126
7	20.8	-1.4	7.1	7.2	28.7	.278	.130
11	20.4	-3.3	11.7	12.1	32.2	.306	.148
1	19.4	-2.4	7.4	7.7	32.9	.274	.124
8	21.5	-3.8	5.3	6.5	28.6	.266	.118
9	20.4	-0.5	7.1	7.1	28.6	.302	.144
5	20.6	+4.1	8.9	20.6	29.3	.322	.172
10	20.6	-0.7	7.3	7.4	31.7	.308	.152
$\bar{x}$	= 20.3	-1.6	7.9	9.2	29.9	.29	.14
Range	=9.1-27.6	-0.5 - 4.1	5.3-11.7	6.5-20.6	27.3-32.9	.266-.322	.118-.172
SD	= 4.10	2.18	1.71	3.93	1.84	.02	.02
r distance, xi =	0.05	-.41	0.07	-0.29	-0.28	-0.41	-0.38
Significance:		p < =.18				p < =.19	p < =.21

Table 37 (Continued)

Trial # Units	Time for Ball Travel Heel Strike to Contact secs	Contact Time secs	Time for Launch to Support Foot Lift secs	Rt. Knee Linear Velocity Just Prior to Contact m/s	Rt. Ankle Linear Velocity Just Prior to Contact m/s
6	.146	.008	.126	.93	19.64
4	.158	.008	.130	2.49	19.38
12	.154	.008	.132	1.17	16.21
2	.162	.006	.126	1.35	18.24
3	.160	.010	.126	1.71	17.18
7	.148	.008	.136	1.87	18.97
11	.158	.008	.134	.55	17.43
1	.150	.008	.132	1.64	18.72
8	.148	.006	.132	.29	19.28
9	.162	.006	.134	.83	19.87
5	.152	.008	.124	2.10	19.11
10	.156	.006	.130	3.45	18.24
$\bar{x}$	= .154	.0075	.13	1.53	18.52
Range	= .146-.162	.006-.010	.124-.136	.29-3.45	16.21-18.87
SD	=0.005	0.001	0.003	0.88	1.11
r distance, xi	=-0.22	0.34	-0.13	-0.38	-0.05
Significance:				p < =.22	

Table 37 (Continued)

Trial # Units	Peak Rt. Knee Linear Velocity m/s	Peak Rt. Ankle Linear Velocity m/s	Δ Rt. Toe Linear Velocity at Contact and Launch m/s
6	11.69	21.00	5.1
4	11.96	20.22	3.3
12	12.48	20.29	4.8
2	12.49	19.43	9.2
3	12.82	21.46	6.5
7	13.51	21.40	3.9
11	22.97	20.85	0.0
1	14.27	19.95	7.8
8	11.77	19.43	7.4
9	13.28	20.03	6.7
5	12.21	20.31	6.8
10	13.78	21.13	8.6
$\bar{x}$	= 13.60	20.46	5.84
Range	=11.69-22.97	19.43-21.46	0.0-9.2
SD	= 3.06	0.70	2.58
r distance, xi	= -0.14	-0.03	-0.35
Significance			

APPENDIX N

Table 38

Subject Center of Gravity Velocities at Contact (m/s)

Trial #	Horizontal	Vertical	Linear
1	3.2	2.2	1.9
2	1.3	0.1	2.3
3	1.8	1.8	2.7
4	1.2	1.6	1.4
5	1.8	1.6	1.4
6	1.8	0.5	2.5
7	1.6	1.8	2.9
8	1.6	.9	3.9
9	3.5	2.1	2.7
10	0.8	1.4	4.1
11	2.5	1.5	2.4
12	2.2	0.9	2.2
$\bar{x}$	1.9	1.3	2.6
SD	0.8	0.6	0.9

APPENDIX O

Table 39

Ball End X-Coordinates Differences* at Various Stages of the Punt

Trial #	Heel Strike mm	Heel Strike Difference	Contact mm	Contact Difference	Launch mm	Launch Difference	In-Flight** (at support foot lift) mm	In-Flight** (at support foot lift) Difference
1	276	14	259	31	266	24	265	25
2	270	20	267	23	261	29	110	180
3	274	16	264	26	288	1	189	101
4	258	32	254	36	272	18	215	75
5	269	21	255	35	227	63	172	118
6	279	11	276	14	271	19	172	118
7	251	39	239	51	239	51	183	107
8	263	27	286	4	280	10	259	31
9	265	25	275	15	282	8	255	35
10	267	23	259	31	269	21	159	131
11	236	54	256	24	263	27	283	7
12	285	5	271	19	284	6	199	91

*Ball Length = 290 mm (11.5"). Differences approximate the extent to which the ball is angled towards the mid-line of the body, and in particular, at contact, approximates the angle of the ball across the foot.

**Large discrepancies have indicated that the ends of the ball were not clearly defined.

Appendix P

```
C*****************************************
C*KSU BIOMECHANICS 'WILDCAT' PROGRAM.    *
C*THIS PROGRAM WILL GENERATE CENTER      *
C*OF GRAVITY, VELOCITY OF THE C OF G     *
C*IN THREE PLANES - LINEAR, HORIZONTAL   *
C*AND VERTICAL; AND 3 PLANE VELOCITIES   *
C*FOR THE 19 JOINT CENTERS.              *
C*****************************************



C**********************************************
C*ORIGINAL PROGRAM WRITTEN BY BOB UMHOLTZ     *
C*AND ART DAYTON, DEPARTMENT OF STATISTICS,   *
C*KANSAS STATE UNIVERSITY.                    *
C**********************************************



C*******************************************************************


C     *    DEFINITIONS OF VARIABLES
C     *    CON =  CONSTANT (IMAGE TO REAL LIFE)
C     *    CUM =  CUMULATIVE TIME
C     *    FMTSPC =  VARIABLE INPUT FORMAT FOR X & Y AND TIME
C     *    I = SUBSCRIPT THAT LOCATES ALL POINTS IN THE PROGRAM
C     *    LC =  LOWER COORDINATE
C     *    UC =  UPPER COORDINATE
C     *    PIVCT =  ORDER OF SEGMENTAL INPUT
C     *    VELX =  HORIZONTAL VELOCITY
C     *    VELY =  VERTICAL VELOCITY
C     *    VELXY =  LINEAR VELOCITY
C     *    XBOD =  X COORDINATE OF C OF G OF BODY
C     *    YBOD =  Y COORDINATE OF C OF G OF BODY
C     *    XC =  X COORDINATE OF A BODY SEGMENT
C     *    YC =  Y COORDINATE OF A BODY SEGMENT
C     *    XP = PRODUCT (SEGMENT C OF G BY WEIGHT PROPORTION)
C     *    YP = PRODUCT (SEGMENT C OF G BY WEIGHT PROPORTION)
C     *    PSEG = % OF BODY SEGMENT USING DEMPSTER'S DATA
C     *     PBW = % OF BODY SEGMENT USING DEMPSTER'S DATA

C     *    WRITE = ORDER FOR THE COMPUTER TO MAKE A STATEMENT.


C*******************************************************************
C* REAL: THIS ESTABLISHES COMPUTER SPACE FOR DATA INPUT.

      REAL*8 FMTSPC(10),SEGMNT(14),PCINT(24),TITLE(10)
      REAL PSEG(14),PBW(14),XC(14),YC(14),XP(14),YP(14),X(60,24),
      Y(60,24),VELX(60,24),VELY(60,24),VELXY(60,24),XBOD(60),YBOD(60),
      XBODC(60),YBODC(60),XYBODC(60),TIME(60)
      INTEGER LC(14),UC(14),PIVOT(24)
      READ(5,18)TITLE,NFRAME,FMTSPC,(LC(I),UC(I),I=1,14),PIVOT,CON,ICUM
```

```
      DO 1 I=1,14
    1 READ(5,19)SEGMNT(I),PSEG(I),PBW(I)
      DO 2 I=1,24
C     *   THE COMPUTER NOW READS IN THE ORDER OF POINTS
    2 READ(5,19)POINT(PIVOT(I))
      DO 6 IFRAME=1,NFRAME
      READ(5,FMTSPC)(X(IFRAME,PIVOT(I)),Y(IFRAME,PIVOT(I)),I=1,24),
     *TIME(IFRAME)
      XBOD(IFRAME)=0
      YBOD(IFRAME)=0
C     *   THIS IS THE START OF THE SEGMENT C OF G CALCULATION
      DO 3 I=1,14
C     *   THIS IS THE FIRST APPLICATION OF DEMPSTER'S DATA
      XC(I)=X(IFRAME,LC(I))+PSEG(I)*(X(IFRAME,UC(I))-X(IFRAME,LC(I)))
      YC(I)=Y(IFRAME,LC(I))+PSEG(I)*(Y(IFRAME,UC(I))-Y(IFRAME,LC(I)))
      XP(I)=XC(I)*PBW(I)
      YP(I)=YC(I)*PBW(I)
      XBOD(IFRAME)=XBOD(IFRAME)+XP(I)
    3 YBOD(IFRAME)=YBOD(IFRAME)+YP(I)
      IF(IFRAME/3*3.EQ.IFRAME-1)GO TO 4
      WRITE(6,20)
      GO TO 5
    4 WRITE(6,21)TITLE
C     *   THIS IS THE WRITE STATEMENT FOR THE TOTAL C OF G INFORMATION
    5 WRITE(6,22)IFRAME,(I,SEGMNT(I),PSEG(I),XC(I),YC(I),PBW(I),XP(I),
      YP(I),I=1,14)
      WRITE(6,23)XBOD(IFRAME),YBOD(IFRAME)
    6 CONTINUE
      WRITE(6,24)
      DO 7 IFRAME=1,NFRAME
    7 WRITE(6,25)IFRAME,XBOD(IFRAME),YBOD(IFRAME)
      WRITE(6,26)
      DO 10 I=1,19,6
      I5=I+5
      WRITE(6,27)(POINT(J),J=I,I5)
      DO 9 IFRAME=2,NFRAME
C**********************************************************************
C     *   CALCULATING HORIZONTAL VELOCITY OF THE SEGMENTS
C**********************************************************************
      DO 8 J=I,I5
    8 VELX(IFRAME,J)=CON*(X(IFRAME,J)-X(IFRAME-1,J))/(TIME(IFRAME)-
     *ICUM*TIME(IFRAME-1))
    9 WRITE(6,28)IFRAME,(VELX(IFRAME,K),K=I,I5)
   10 CONTINUE
      WRITE(6,29)
      DO 13 I=1,19,6
      I5=I+5
      WRITE(6,27)(POINT(J),J=I,I5)
      DO 12 IFRAME=2,NFRAME
C*****************************************************************************************
C     *   CALCULATING THE VERTICAL VELOCITY OF THE SEGMENTS
C**********************************************************************
```

```
      DO 11 J=I,I5
   11 VELY(IFRAME,J)=CON*(Y(IFRAME,J)-Y(IFRAME-1,J))/(TIME(IFRAME)-
     *ICUM*TIME(IFRAME-1))
   12 WRITE(6,28)IFRAME,(VELY(IFRAME,K),K=I,I5)
   13 CONTINUE
      WRITE(6,30)
      DO 16 I=1,19,6
      I5=I+5
      WRITE(6,27)(POINT(J),J=I,I5)
      DO 15 IFRAME=2,NFRAME
C*****************************************************************
C     *   CALCULATING THE LINEAR VELOCITY OF THE SEGMENTS
C*****************************************************************
      DO 14 J=I,I5
   14 VELXY(IFRAME,J)=SQRT(VELX(IFRAME,J)**2+VELY(IFRAME,J)**2)
   15 WRITE(6,28)IFRAME,(VELXY(IFRAME,K),K=I,I5)
   16 CONTINUE
      WRITE(6,31)
      DO 17 IFRAME=2,NFRAME
C*************************************************************************
C     *   CALCULATING THE HORIZONTAL VELOCITY OF THE C OF G OF THE BODY
C*************************************************************************
      XBODC(IFRAME)=CON*(XBOD(IFRAME)-XBOD(IFRAME-1))/(TIME(IFRAME)-
     *ICUM*TIME(IFRAME-1))
C**********************************************************************
C     *   CALCULATING THE VERTICAL VELOCITY OF THE C OF G OF THE BODY
C*************************************************************************
      YBODC(IFRAME)=CON*(YBOD(IFRAME)-YBOD(IFRAME-1))/(TIME(IFRAME)-
     *ICUM*TIME(IFRAME-1))
C*************************************************************************
C     *   CALCULATING THE LINEAR VELOCITY OF THE C OF G OF THE BODY
C*************************************************************************
      XYBODC(IFRAME)=SQRT(XBODC(IFRAME)**2+YBODC(IFRAME)**2)
   17 WRITE(6,32)IFRAME,XBODC(IFRAME),YBODC(IFRAME),XYBODC(IFRAME)
      WRITE(6,21)
      RETURN
   18 FORMAT(10A8/I2/10A8/28I2/24I2,F6.0,1X,I1)
   19 FORMAT(A8,F3.3,F4.4)
   20 FORMAT(' ')
   21 FORMAT('1',10A8/)
   22 FORMAT(' FRAME',T11,'SEGMENT',T26,'BODY',T41,'%',T58,'X',T75,'Y',
     *T85,'PROP',T102,'X',T119,'Y'/' NUMBER   NUMBER',T25,'SEGMENT',
     *T40,'SEG',T57,'C/G',T74,'C/G',T85,'BODY',T101,'PROD',T118,'PROD'/
     *T86,'WT'/T4,I2,(' ',T13,I2,T25,A8,F10.4,2F17.4,F12.4,F16.4,F17.4))
   23 FORMAT(' THE CENTER OF GRAVITY OF THE BODY IS (',F12.4,' , ',
      F12.4,' )')
   24 FORMAT('1THE COORDINATES OF THE THEORETICAL CENTER OF GRAVITY',
     *2(/),' FRAME',T22,'X COORDINATE',T42,'Y COORDINATE'/)
   25 FORMAT('  ',I2,2X,F27.4,F20.4)
   26 FORMAT('1VELOCITIES OF BODY PARTS IN HORIZONTAL PLANE')
   27 FORMAT('-FRAME',6(12X,A8))
   28 FORMAT('  ',I2,2X,6F20.4)
   29 FORMAT('1VELOCITIES OF BODY PARTS IN VERTICAL PLANE')
   30 FORMAT('1VELOCITIES OF BODY PARTS IN A LINEAR DIRECTION')
   31 FORMAT('1VELOCITIES OF CENTERS OF GRAVITY IN THREE DIRECTIONS',
     *2(/),' FRAME',T22,'HORIZONTAL',T42,'VERTICAL',T62,'LINEAR'/)
   32 FORMAT('  ',I2,2X,F25.4,2F18.4)
      END
//GO.SYSIN DD *
BIOMECHANICAL PARAMETERS OF PUNT KICKING AN AMERICAN FOOTBALL
```

```
51
(10X,12F5.3,/,10X,12F5.3,/,10X,12F5.3,/,10X,12F5.3,/,F3.3)
 1 2 2 3 4 5 5 6 6 7 8 9 91010111213131414151617171 81819
0102030405060708091011121314151617181920212223241.05
TRUNK    4505140
HEADNECK1.00790
R THIGH 4330965
R L LEG 4330450
R FOOT  4290140
L THIGH 4330965
L L LEG 4330450
L FOOT  4290140
R U ARM 4360265
R L ARM 4300155
R HAND  5060060
L U ARM 4360265
L L ARM 4300155
L HAND  5060060
CRUTCH
STERNUM
EAR TRAG
RT FEMUR
RT KNEE
RT ANKLE
RT TOE
LT FEMUR
LT KNEE
LT ANKLE
LT TOE
RT SHLDR
RT ELBOW
RT WRIST
RT HAND
LT SHLDR
LT ELBOW
LT WRIST
LT HAND
```

```
C     *THE ABCVE IS AS FCLLCWS:
C*           1. TITLE OF THE PROJECT
C*           2. THE NUMBER CF FRAMES TO BE ANALYZED
C*           3. THIS IS THE FCRMAT CARD FOR INPUT DATA
C*           4. THIS DIFFERENTIATES BETWEEN THE LOWER & UPPER COORDINATES
C*           4. THIS DIFFERENTIATES LOWER & UPPER COORDINATES
C*           5. THERE ARE 24  BITS OF INFORMATION PER ANALYZED
C*              FRAME - 19 JOINT CENTERS & 5 FOR IMPLEMENTS ETC.
C*           6. LOCATION OF THE C OF G FOR EACH SEGMENT (DEMPSTER)
C*           7. THE ORDER OF READING THE COORDINATES

C*****************************************************************************
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BIOMECHANICAL PARAMETERS OF PUNT KICKING

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The purpose of this study was to establish biomechanical parameters of punt kicking an American football, and from these parameters isolate specific factors associated with superior performance. A kicker from a team in the Big 8 Football Conference was filmed at 500 fps using a Red Lakes Laboratory Locam Camera. Twelve trials were analyzed with a Vanguard Motion Analyzer, a digitizer linked with an on-line paper tape punch and automated teletype printer.

The film data was further reduced by computer using the 'Wildcat' biomechanics Fortran program. Data was presented on various limb segment velocities, the center of gravity displacement and specific variables: number of approach steps, the role of the support foot, ball release from the hands, height of the ball from ground at contact, kicking leg action, foot to ball contact, ball position relative to the foot at contact, foot velocity, ball launch angle, direction of the follow through and resultant action of the support leg. For superior performance it was concluded that the effective transfer of force to the ball was highly important. This effective transfer involved the point of contact with the ball and angle of the ball relative to both the foot and the horizontal at contact. Optimums were suggested for each of these factors, as well as an optimum launch angle of approximately fifty degrees.