A BIOMECHANICAL COMPARISON OF THE LONG SNAP TO PUNTER BETWEEN HIGH SCHOOL AND UNIVERSITY LEVEL FOOTBALL PLAYERS

by

Michael George Chizewski

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Dedication

All for my mystical wife,

Ruth.

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Abstract

Few attempts were found in the past five decades of football research to quantify measures of long snap biomechanics. The purpose of the study was to compare the joint movements, velocities and body positions used to perform fast and accurate long snaps in high school (HS) and university level (UNI) athletes. Other purposes were to determine the kinematic variables related to greater release velocity within these groups (Pearson product-moment correlation); also to determine which variables are significant predictors of release velocity or total snap time* (TST) for HS, UNI, and both groups combined* (stepwise multiple regression analysis). Ten HS and ten UNI subjects were recruited for filming. The athletes performed snaps at a target with the fastest and most accurate trial selected for analysis. Eighty-three variables were measured using Dartfish TeamPro 4.5.2 digital video analysis software, with Microsoft Excel and SPSS 16.0 being used for statistical analysis. Several significant comparisons to long snapping technique between groups were noted during analysis, however, the body position at critical instant showed the greatest number of significant differences. The UNI athletes had a significantly greater release velocity (15.15m/s) and left elbow extension velocity (752°/sec) than the HS group (13.21m/s and 498°/sec). HS athletes had significantly higher release heights and release angles. TST (release time + total flight time) had the strongest correlation to release velocity in HS ($r=-0.915$) and UNI snappers ($r=-0.918$). The study suggests high school long snappers may benefit from less elbow flexion and more knee flexion in the backswing (set position) to increase release velocity. University long snappers were found to benefit from increased left elbow extension range of motion (force production) and decreased shoulder flexion at critical instant to increase long snap release velocity.

Chapter 1

Introduction

The player positions in the game of North American football are exclusive in sport in that they all require significantly different technique and skill. No two positions are coached or performed the same way, and at elite levels of play it would likely not be possible for players or coaches to alter their position on or off the field without considerable preparation. In addition to this logistical coaching challenge, winning game plans incorporate three completely different subsets of the game: offense, defense, and the special teams. Each of these sub-units has 12 players per team on the field at any given time in the Canadian game, compared to 11 players in the American game. The special teams are also known as the "suicide squads" (DeLuca, 1978) for their high incidence of injury due to multiple open field high velocity collisions. These squads are the groups of players responsible for kickoffs, punts, field goal attempts, and the associated defensive cover tactics for these units. 'Special teams' units incorporate multi-talented athletes who are not only responsible for executing specific assignments with or without the ball, but also for effective and aggressive down field coverage to limit the return of the opposing team. Proficiency in special teams is a vital component to football success because of the likelihood of immediate scoring or large changes in either team's field position during these plays. These special teams include all the kicking teams; and the long snap to punter is a further division of the kicking game.

One of the most important plays in a football game that can dictate future field position is the punt (Ohton, 1988). The two essential players for the punt are the centre (who is usually the long snapper in the kicking formation) and the punter. The snapper is responsible for delivering the football, and the punter is then responsible for receiving the football and kicking it downfield strategically. The offensive team may choose to punt if they are facing their final offensive attempt to gain first down yardage (third down in Canadian football or fourth down in American football), and the distance to the first down marker is such that it does not warrant the risk of losing possession. The punt is a deep kick of the ball, in an attempt to maximize the change in field position before giving possession of the ball to the opposing squad.

In order to execute the punt, the punter will stand up to 13.72 m (15 yards) behind the line of scrimmage (Bobo & Dykes, 1998), although each snapper/punter tandem may adjust this distance slightly with younger skill levels using shorter distances. Each time a punt is attempted, the risk of an errant snap is present; each errant snap represents the potential for large alterations in field position, or even immediate points being scored by the opposing team. This increased potential for error suggests that the more times a team is placed in a punting situation, the greater the demand on all players involved in the punt, beginning ultimately with the long snapper's delivery of the football.

The number of punting attempts appears to vary depending on the level of play. The 2008 Canadian Football League (CFL) average for number of punts per game was 6.60 over 18 regular season games per team (Canadian Football League, 2008). The university level Canadian Interuniversity Sport (CIS) average was 8.25 punts per game over eight regular season games per team (Canadian Interuniversity Sport, 2008) and the Canadian Junior Football League (CJFL) average per team over eight games was 7.59 punts per game (Canadian Junior Football League, 2008). Canadian high school leagues do not tend to record punts per game, only average yardage per punt. In personal discussion with four high school team coaches in Winnipeg, punts were estimated to be performed an average of five to six times per game. Ron Dias, a Canadian high school football recruiter said that, "… in the high school game, some teams may even choose not to punt and gamble for the required yardage each time due to ineffective punting on their team" (R. Dias, personal communication, August 28, 2008), which may bring down the average high school punting numbers. An estimate of up to six punts per high school team per game was deemed reasonable by the researcher to continue. The National Football League (NFL) punting average was the lowest reported at 4.56 punts per game over 16 regular season games (National Football League, 2008). This may be expected since the American game allows offensive teams an extra down, or opportunity, to gain the necessary 10 positive yards when compared to Canadian football rules. Regardless of level of play, with some teams punting nearly ten times in one game (Figure 1.1), the ability, or inability to perform successive and successful snaps to the punter can significantly affect either team's field position. Each punt attempt places the long snapper in a possibly game-changing moment, where a fast and accurate snap is the first crucial step to a successful kicking outcome.

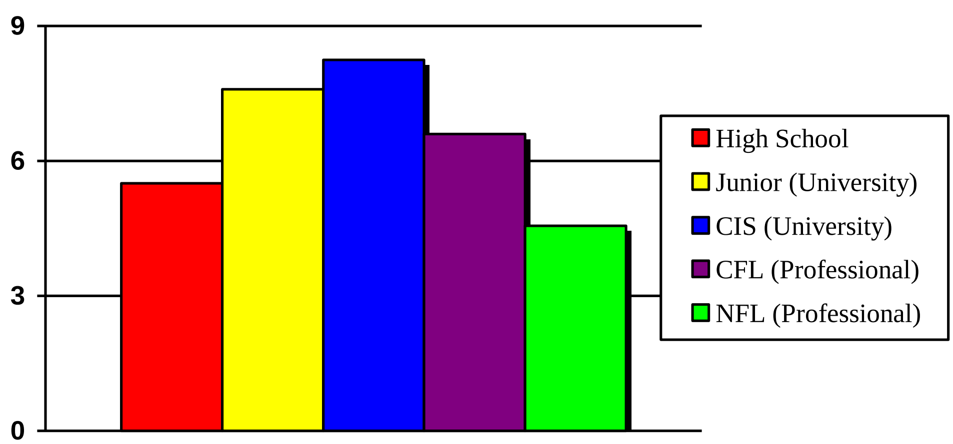

Figure 1.1: Punt distribution average per game (per team in 2008) across various leagues. (Sources cited in previous paragraph.)

According to the rules of play (CFL, 2008):

> "At the commencement of a scrimmage play, one Team A player (the Centre) shall take position facing the opponent's Goal Line with the ball on the playing surface immediately in front and shall put the ball in play by snapping it back between the legs in one continuous motion to another Team A player behind the line of scrimmage. The ball must leave the hands of the Centre, who shall not touch the ball again until it has been in the possession of another player."

The main responsibility of the long snapper in a punting situation is to perform a fast and accurate spiral pass. A spiraling ball is one whose rotation is occurring mainly about its longest axis (DeLuca, 1978), or the imaginary line drawn through the inner portion of the ball going from tip to tip. The long snapper's following responsibilities are then to block defenders in the assigned direction, and to cover the punt downfield (Zauner, 1985). The long snapper is a difficult and specialized position, and often requires a selfless player who is prepared for many hours of extra practice. The successful long snapper must also be an athletic individual. A player who cannot throw a football while standing upright is going to have limited success propelling it through his legs from an upside down position (Catapano, 1998). In discussion with Edmonton Huskies (CJFL) president and former All-Canadian defensive lineman, Craig Alloway also noted that it requires a "dedicated and focused individual who can snap a football consistently if defenders are trying to force his head into his body while he is doing it" (C. Alloway, personal communication, August 18, 2008). Although the punter is an asset to any team, not even the greatest punter can be successful without a perfectly delivered football from the long snapper.

The need to analyze the long snap is supported by the skill's particularly high level of difficulty, to perform and to master. The snapper must first of all sight a target while looking at it between his legs. This means the intended target is not only behind the athlete, but also upside down, which makes aiming adjustments incredibly challenging. The uniqueness of the skill means that the long snapper may only improve the performance of skill by practicing the long snap; as few other skills will be able to transfer to this sport specific situation. Transfer is based on the number of common elements shared by two skills. When the learning of a new skill or its performance under novel conditions is influenced by past experience with another skill or skills (Coker, 2004), transfer is present. The long snap is an excellent demonstration of one of these “novel conditions”, where it is difficult to instruct a new learner to imagine they are performing another skill in hopes of improving their long snap. This means that coaches must identify potential long snappers early in the season and in the player’s career, in order to allow ample time to develop the skill in potentially able players.

The long snapper, within the context of the game, is constantly being reminded that football is a full contact sport; since contact is invariably drawn by the defensive player as soon as the long snapper initiates movement. This means that the long snapper will almost always be hit before he is able to properly prepare for contact. Unfortunately, this often places the long snapper in a particularly vulnerable position; bent over with the head tucked between the legs when this contact occurs. The unprotected back of the neck is therefore exposed. This places the posterior portions of the cervical vertebrae at risk of injury. This vulnerability adds to the difficulty of the skill, since the snap must be executed properly knowing full well that the defensive player lined up on the other side of the ball is charging as soon as the ball is moved.

Besides the obvious difficulty of the skill, long snapping also appears to be unrivalled in football (perhaps in sport) as far as expectations are concerned. The long snapper is expected to deliver a fast and accurate ball to the punter each and every execution, with little room for error. This researcher's personal observation through playing and coaching football is that a 'bad snap' is often considered unacceptable by the coaching staff. Zauner (1985) states that professional players are expected to be completely automatic with no mistakes in game action. This expectation is placed on the long snapper in a game where any other player on the field is praised for much lower success rates at their particular position. Bryan Pittman, the long snapper for the Houston Texans professional team in the NFL, had a professional streak of 598 consecutive successful snaps broken in 2007 (Pittman's personal streak extended back almost ten years through his entire university and most of his high school career). After a single missed snap which resulted in a fumble and a touchdown by the visiting San Diego Chargers team, Pittman was berated by coaches on the sidelines and by reporters in the press. Although his own disappointment was overwhelmingly evident immediately following the miss, it only fuelled the public scrutiny he faced for many months following the mistake. The Houston Chronicle's (October 29, 2007) opening paragraph in an article which appeared the day after the game read:

> "Bryan Pittman went behind the Texans bench to regroup. He made it clear he didn't want anyone to talk to him. For the first time in 598 snaps in the NFL, Pittman botched one. He stood behind the bench, trying to accept what had just happened and analyze what went wrong." (Manfull, 2007)

He *botched* one, when it should have read he botched *one*. Pittman's 598 completions for 599 attempts convert to a success rate of higher than 99.83%. This is nothing short of incredible, but alas, it is not perfect. It is difficult to find another football comparison that focuses so intently on single errors. The most successful field goal kickers in the Canadian and American games had field goal percentages of 89% and 84.9% in 2008. Quarterback pass completion percentages peaked at 69.9% (CFL, 2008) and 68.9% (NFL, 2008). The long snapper may receive prolonged abuse from fans and coaches, and are even occasionally relieved of duty following a single snap that sails over the punter's head and results in a turnover, negative field position, or points scored by the opposition. "Deep snapping is a very important part of the game, in that as long as no one really knows your name, you're probably doing your job" (Kendall Gammon, 2000).

Although the high school or university distance snapper is not subject to quite the same criticism or expectation as the professional, an unforced error while delivering the football to the punter may result in a game-changing play at any level. Early analysis of this unique and difficult skill at the high school and university level may assist future long snappers in their quest for anonymity.

Purpose of the study

P_1 - The primary purpose of the study is to determine the biomechanical differences that exist between high school (HS) and university level (UNI) long snappers when delivering the football to the punter.

P_2 - The secondary purpose of the study is to identify the kinematic variables which are associated with higher release velocity in HS and UNI long snappers; and to determine the key biomechanical variables which may be able to predict a fast and accurate snap.

Rationale for the study

As the sport of North American football evolves from its inception in 1876, and teams have greater resources to improve all aspects of the game, more emphasis is being placed on the success of special teams. The long snap, as one aspect of the kicking game which is one aspect of the special teams, is not exempt from this development. With a fast and accurate snap, the punting sequence can be initiated faster. With a single poor snap, the opposing team can easily gain the advantage in field position, thus, better positioning the offense for scoring opportunities (Blegen, Goldsworthy, Stulz, Gibson, Street, & Bacharach, 2005). It is necessary to evaluate and understand the long snap, as an integral part of the special teams, for a more complete understanding of the key characteristics involved with the skill.

Besides a recent study by Blegen et al (2005) and Ohton's (1988) kinesiological look at the snap which focused on strength and conditioning for the snapper, no previous attempt has been located in the literature to quantify skill level differences in mechanics during the snapping motion. The first descriptive analysis of the long snap located by this researcher was conducted by Henrici (1967), who estimated the percentage of contribution by each body segment to the linear velocity of the football. Rubicam (1965) and Slebos (1968) provided research on long snapping, but limited their investigation to comparing the visual (looking backward between the legs during delivery) and non-visual (keeping the head and eyes facing forward during delivery) methods of performing the skill. Limited scientific studies have been conducted describing any mechanics of the long snap, and many of the writings are not research based. DeLuca (1978) makes only one reference to the centre's distance snap to punter and states that "a centre capable of making a good snap is essential". Bobo & Dykes (1998) comment briefly on the long snap stating that snaps released too soon will be too low, and snaps released too late will be too high. The knowledge gaps that exist between biomechanical knowledge and the coaching aspects of the long snap demand more and better knowledge to differentiate between what is being taught from what is being performed. "Too often, the coaching of a skill such as long snapping resides in mythology, with no data to support the methods taught" (Blegen et al., 2005). The study of the application of mechanics to athletic performance may provide a direct and meaningful approach to professionals and students in education and athletics (Scott & Cureton, 1952). This fundamental concept has not changed, but the ability to accurately measure biomechanical performance has greatly improved.

This study was designed to use current digital video analysis software to identify the kinematic and biomechanical characteristics of more experienced and possibly more skilled university athletes, when compared to less experienced and possibly less skilled high school long snappers from amateur football teams. This will be done in anticipation of finding characteristics of the skill at two levels that an educator or coach can focus on to improve their athlete's skill performance. This will also be done in hopes of identifying variables that are related to, or that may be able to predict long snaps with higher release velocity. Although a three group study design that included professional players was originally preferred, it was unlikely that it would be possible to recruit professional players for the study which called for the removal of that group from the study.

Hypotheses

H_1 • The release velocity of the long snap to punter will be greater in the university level athletes than in the high school athletes.

H_2 • The movement patterns and kinematic variables (joint movements and velocities) of the long snap to punter that are determined to be significantly related to release velocity will differ between high school and university level long snappers.

H_3 • The variables identified as possible predictors of long snapping release velocity will differ between high school and university level athletes.

The rationale for these hypotheses is based on the potential differences between the two groups of long snapping specialists. The UNI group is not only older, but will likely also have the advantage in total hours coached, physical maturation and muscular development. These differences between the groups are the basis for the predicted results.

Delimitations

The study is delimited to:

1) Twenty amateur Canadian football players, aged 16-30, who have already been selected, or are in the process of being selected for a high school or university (Junior or University level) team. Athletes chosen were similar in developmental level with respect to their instruction and experience and all incorporated two hands in their snapping delivery technique.

Limitations

This study is limited by:

1) The sample size of the study (N=20) is small, necessitating caution in extrapolation of the data to a larger football player population.
2) The subject data was collected in a controlled setting, as opposed to a game setting which may affect the mechanics of subjects resulting in decreased validity.
3) The ability to generalize the results to younger athletes may be difficult due to the post-pubescent ages of the subjects in this study.
4) Although filming sessions were restricted if conditions were extreme, weather provided an uncontrolled variable for the duration of this study.

Brief description of the skill[*]

Preliminary movements

Stance

The football is placed on the ground by the official with the laces facing the ground before the centre approaches the line of scrimmage. The ball should be perpendicular to the line of scrimmage (pointing forwards and backwards to the long axis of the playing field). The stance is the position the athlete assumes prior to movement. The long snapper should assume a stance that is wider than shoulder width apart (Figure 1.2). If the legs are too close together, the base of support is smaller and the centre of gravity is higher, thus increasing the instability of the athlete.

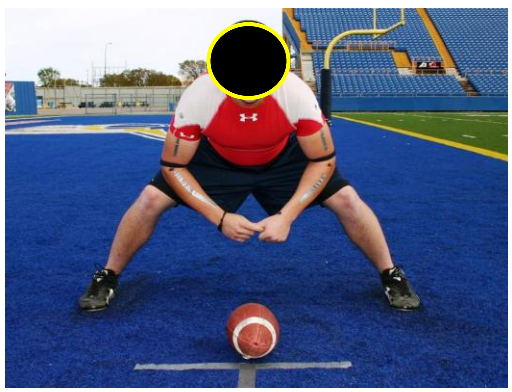

Figure 1.2: Ball placement and athlete stance for distance snap to punter.

A narrow stance would also limit the range of shoulder and arm motion in the backward direction; as well as limiting the summation of velocities of the arm, forearm, and hand segments (Fracas & Marino, 1989). If the legs are too far apart, the athlete's range of motion at the hip and knee may be limited during force production due to high degrees of hip abduction and possibly lateral rotation of the hip. This limited or decreased

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[*] Throughout the ensuing discussion, it is assumed the long snapper is right-handed.

range of motion will decrease the ultimate force applied to the ball and result in decreased velocity of the snap. A strong, balanced stance that takes stability and range of motion into account is a necessity. It is suggested that stability and range of motion are possible with the feet slightly wider than shoulder width apart and was examined in the study.

The feet are both positioned parallel (to the line of scrimmage), or only slightly staggered. It is important to keep the feet parallel to better control the direction of the football in flight. The long snapper is able to project the ball directly behind him if he begins with a parallel stance (Fracas & Marino, 1989). Special teams coach (University of Manitoba Bisons), and former university long snapper, Lloyd Orris re-iterates to his long snappers that "the ball goes where the butt points" (L. Orris, personal communication, October 2008). With a parallel stance, it is likely the long snapper will have more consistency in snapping the ball straighter.

Since the desired target of the long snapper is the punter's right hip, it is more common to see a slight deviation backward from parallel with the left foot. This slightly staggered stance places the left hip slightly behind the right hip, causing the buttocks to point at the right hip of the punter. The distance of the toes from the line of scrimmage may vary a great deal between athletes and will be discussed further in the backswing phase of the skill. Coaching articles (Grindle, 1999, St. Leger, 1989) suggest the long snapper place the feet far enough back from the line of scrimmage to necessitate a high degree of shoulder flexion in order to place the football on the line of scrimmage. By doing this, the athlete is in a position that will allow for a greater range of motion during force production; which contributes to release velocity by having a greater range of motion through which to impart force to the football.

Grip

Once the centre has established the stance, the ball can be gripped. There are three basic grip techniques: dominant hand, symmetrical, or one-handed. The dominant hand grip is used for the long snap to punter; therefore this initial description of skill will focus on the dominant hand grip. Some discussion of the symmetrical and one-handed grips will be included in the literature review.

The grip incorporates the right hand as the throwing hand, and the left hand as the guide hand. The right (dominant) hand grips the ball as if to throw a forward, overhead pass (Fracas & Marino, 1989), with at least the three, four, and five digits usually on the laces (Figure 1.3). Some of these variations can be attributed to hand size, but the athlete's skill level, strength, or previous instruction all play a role in an individual's hand or finger placement for passing the football. The right index finger is placed near the front white line of the ball, while the middle finger usually rests on the top of the laces. The thumb wraps around the ball, and the remaining fourth and fifth fingers rest along the laces.

Figure 1.3: Individual variations of the quarterback's grip for the overhead pass.

Regardless of variations, all "throwers" whether it is over the head or between the legs, will incorporate fingers on the laces in the grip of the dominant hand. By placing the fingers on the laces, the athlete is able to impart more spin to the ball due to increased friction between fingertips and ball, which prevents slippage and produces the rotation required for delivery (Fracas & Marino, 1989). As the ball is released from the fingertips, the longitudinal axis of the ball will ideally be the singular axis of rotation, and the pull of the fingers on the laces are the applied force (acting at some distance to the axis). When a force is applied on a body or object away from the axis of rotation, torque is generated, angular momentum is produced, and rotation occurs. It is this torque that creates the angular momentum, seen as spinning (or spiraling) of the football. A ball that spirals about the long axis is more stable in flight and will therefore present the smallest possible cross-sectional area to the onrushing air (Gay, 2004). By decreasing the effect of the wind and the onrushing air, the angular momentum of football is conserved longer. This should allow the perfectly spiraling football to fly farther and faster than a ball that is wobbling, or rotating about more than one axis.

The centre uses both hands for the grip of the long snap (Figure 1.4). The right hand "cups" the ball on the bottom by flexing the right wrist, keeping the fingers on the laces. The left hand, or guide hand, should be placed on top of the ball in a wide spread position with the top seam underneath the index or middle finger (Grindle, 1999). The left hand acts as a guide for a straight, direct snap (Fracas & Marino, 1989). By spreading the fingers of the left hand, equal force is distributed over the top half of the football. This is important because as the ball is "thrown" between the legs, the left hand is responsible for controlling the height of release. If an even force distribution is being placed on the top of the ball, then the leading point of the ball will stay down and keep the ball from going too high during flight. It is also important to spread the fingers of the guide hand to keep the ball from being pushed to one side or the other (for lateral or side to side accuracy). The exact position of the left hand is variable, leaving room for individual preference (Harrington, 2003). Some of the common variations include having the index or middle finger directly on the seam instead of dividing them (Figure 1.4.). Athletes are often told to imagine making the letter T with the index or middle finger of the left hand and the thumb of the right hand.

Figure 1.4: Two separate snapper's guide hand placement; with both athletes showing digit three (middle finger) directly on the top seam of the football.

Backswing

The backswing phase is marked by the end of the movements occurring away from the desired direction of force production. The long snap is somewhat unique since the athlete must pre-set the body in a "ready" or pre-loaded position while waiting to initiate the snap to punter. This "ready" position is the backswing since nearly all movements from here will be in the backward, or force producing direction. The study will call this ready position the backswing phase of the long snap although it is held for some time before force production begins and not all joints follow suit. The elbows appear to be an exception as long snappers were observed during pilot study and data filming to flex at the elbows prior to extending them.

Apart from the elbows, this situation removes a great deal of the rebound or elastic contribution of muscle and tissue to the snap, unlike most throwing motions that rely on the backswing to stretch the muscle quickly prior to maximal force production. Since the body is held in the backswing position before force production in the long snap, there is little eccentric contraction occurring immediately prior to the concentric contraction of the muscles involved. This means the athlete must fire the necessary muscles concentrically from a static position, which may limit the potential muscle force available for the snapper to perform the skill.

In the backswing position, the athlete is in a long and wide stable position. The base of support is large enough to provide stability, without hindering the range of motion of the active joints. The weight of the body should be balanced over the feet, with little weight on football itself. This is achieved by placing the centre of gravity directly above the posterior line of the triangular base of support. In this position, the line of gravity will fall directly between the feet, contributing to the balance and stability of the athlete. The hips and knees are flexed to simulate a “ready” or athletic positioning of the body, while the trunk is often tilted slightly downward from an imaginary horizontal line.

The football should be positioned well in front of the body to necessitate a high degree of shoulder flexion and elbow extension when placing it on the line of scrimmage (Blegen et al, 2005) (Figure 1.5.). This may allow the long snapper more time to set up for blocking after the snap by being positioned further from the line of scrimmage, and may also increase the velocity of the ball by increasing the range of motion of the shoulder extensor muscles during the delivery of the snap.

Figure 1.5: Side and front views of the backswing position in the long snap.

If the range of motion of the muscles is increased, the potential velocity of the ball may also increase due to the impulse-momentum relationship. The impulse-momentum relationship states that the impulse on a body or object (the football) is equal to the change in momentum of the football, or $I = \Delta M$; where I is impulse and M is momentum. This formula can be broken down further to state that $F \bullet t = m \bullet v_{final} - m \bullet v_{initial}$; where F is the linear force applied (in Newtons), t is the time over which that force is applied (in seconds), m is the mass of the football (in kilograms), and v is the linear velocity of the football (in meters/second).

Therefore, if the shoulders are flexed more, they will have a greater range of motion over which to extend and apply a linear force to the ball. If the range of motion is greater, then the time over which the shoulders extend is also greater. For this discussion we will assume that the force applied by the shoulder extensors (F) is a constant during force production, the mass of the football does not change, and the initial velocity of the football is 0 m/s. This means that if the time is increased, then the resultant impulse is also increased. If the total impulse is increased, then the change in momentum of the football is also increased (or the final momentum since initial momentum is 0). Since the mass of the football remains constant, then this change in momentum can be attributed to an increase in the final velocity of the football.

Force producing movements

The actual motion of the snap involves a powerful, bilateral arm swing. It occurs in one continuous motion (Figure 1.6.) with the elbows flexing first, then swinging directly back through the legs of the centre (Catapano, 1988). The posterior upper arm is also contacting the thighs as the centre attempts to, in one fluid motion, bring the ball back and up rapidly through his legs (Grindle, 1999). The elbows continue to extend, the shoulders medially rotate, the forearms pronate, and the wrists flex and adduct until critical instant. The centre's priority is to get the ball to the punter as quickly and accurately as possible.

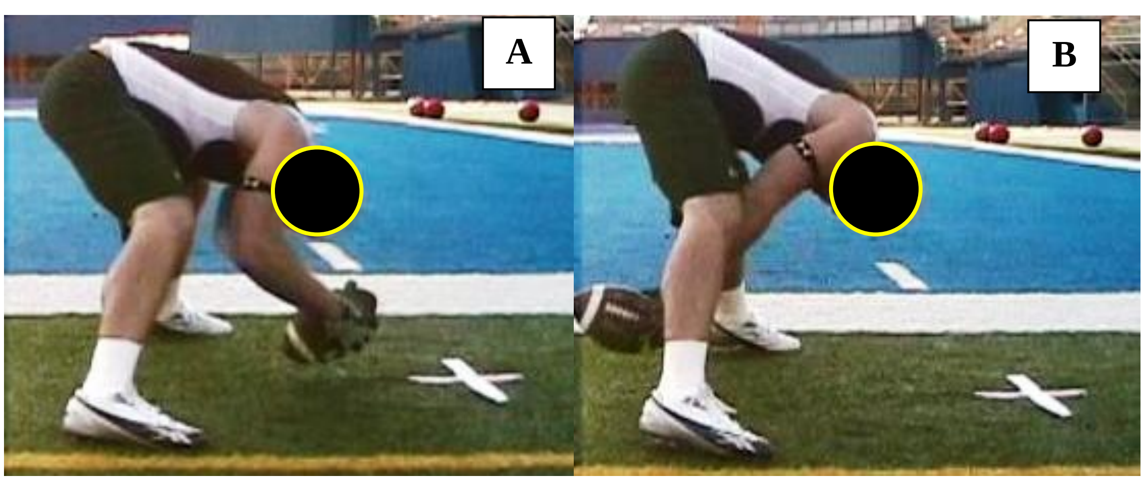


Figure 1.6: Force production phase of the long snap to punter shown midway through the phase (A), and just at the end of force production (critical instant or release) (B).

The knees are the first to extend along with slight hip extension and plantarflexion at the ankles. The extension of the joints in the lower body serves to provide more room for adequate upper body clearance and faster velocities may contribute to greater force production. If the arms have more room to swing, they can snap the ball with longer levers without contacting the ground with the ball (during elbow extension). This will contribute positively to the horizontal velocity of the football at release. An increased range of motion for the upper body increases the time that force is imparted to the ball and thereby increases the final velocity of the football as described by the impulse-momentum relationship.

Extension of the shoulders and elbows along with flexion of the wrists may provide the majority of the force required to project the ball with a high linear velocity (Henrici, 1967). Velocity is calculated as $V = d/t$; where V is linear velocity, d is the displacement of the football, and t is the time over which the displacement occurs. The medial rotation of the shoulders, pronation of the forearms, and flexion and adduction of the wrists provide the force required to impart spin to the ball, or throw with a higher angular velocity. Angular velocity is calculated as $\omega = \theta/t$; where ω is angular velocity, θ is the angular displacement of the football, and t is the time over which the angular displacement occurs.

Similar to the linear discussion, if the range of motion of muscles involved is increased, the angular velocity of the ball (speed of spiral) should also increase as described by the angular impulse-momentum relationship. The angular equivalent of the impulse-momentum relationship states that the angular impulse on a body or object (the football) is equal to the change in angular momentum of the football, or angular $J = \Delta H$; where J is the angular impulse and H is angular momentum. This formula can be broken down further to state that $T \bullet t = I \bullet \omega_{final} - I \bullet \omega_{initial}$; where T is the total torque applied (in N•m), t is the time over which that force is applied (in seconds), I is the moment of inertia of the football (in kg•m^2/s), and ω is the angular velocity of the football (in °/s or rad/s). If the range of motion of the muscles is greater (which increases the time of force application), or the applied torque is greater, then the resultant angular velocity of the football will also be greater (assuming the moment of inertia of the football does not change).

Airborne phase

An airborne phase is often present between force production and critical instant of the long snap. This is visible as backward movement of the feet through delivery. The airborne phase appears to happen just prior to, or during the release of the football. As the ball is released, the centre should have a slight sliding of the feet backwards (Grindle, 1999) in the direction of the snap (Figure 1.7.). This may help to keep the athlete from raising his hips or buttocks too high in the air (Grindle, 1999) by pushing off with the toes in a backward direction during forceful plantarflexion.

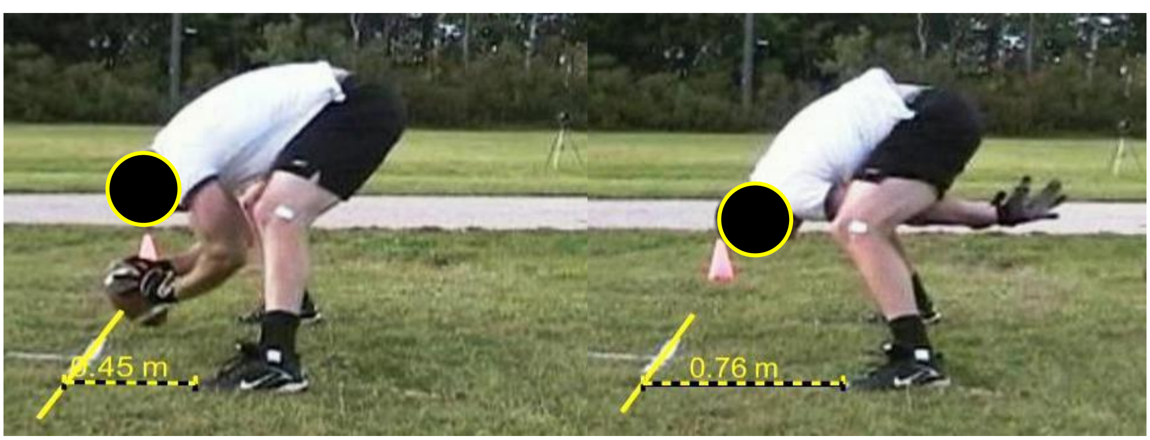


Figure 1.7: Airborne phase demonstrated by the movement of the feet backwards occurring during the delivery of the long snap.

The snapper is also trying to keep the hips and buttocks down to keep the ball from releasing at too steep an angle and going above the desired target area, or over the punter's head. By producing an airborne phase and moving backwards toward the punter, the snapper is potentially flattening the arc of delivery which may improve the accuracy of delivery. The arc is the semi-circular path of the hands as they rotate about the shoulder joint. Flattening the arc refers to keeping the hands lined up with the target for as long as possible through the delivery which is accomplished by leaving the ground just prior to, or during the release. This extended time of alignment will allow the long snapper to have a greater margin of error through the timing of the release. This greater margin of error may make it easier to consistently hit the desired target.

By coinciding the airborne phase with release, the athlete may also be able to transfer some of the backward momentum of the body to the football. Momentum is the product of mass and velocity, or $M = m \cdot v$; where M is momentum (in kg•m/s), m is mass (in kg), and v is velocity (in m/s). The body's centre of mass will be given a horizontal velocity and resultant momentum by the sliding movement of the body in the direction of the snap. This momentum of the body may now be added to final linear velocity of the arms and hands to further increase the linear velocity of the ball at release. Experienced snappers, whose release velocities were greater, were found to slide more towards the target during the snap (Blegen et al, 2005). The beginning and the end of the airborne phase can be measured by calculating the distance the feet move backwards during the snap. The airborne phase occurrence will be investigated further in this study for its relationship to long snap release velocity as well as its strength as a possible predictor of release velocity.

Critical instant

The critical instant, or release, is the instant the football leaves the hand and the athlete is no longer able to impart force to the projectile. The critical instant will see the athlete flexed further forward at the trunk than in the backswing position. This will allow his arms to release freely between the legs. In the release phase, the elbows have approached nearly full extension. Shoulder medial rotation will supplement the forearm pronation (Ohton, 1988) to give the ball its spiral in flight. The football is "pushed" with the left hand, and "pulled" with the right hand through the snap. The left hand release point is usually the side of the index finger as the left hand pushes across the top of the ball. The right hand release point is usually the middle digit as it pulls on the laces. This differs from the overhead quarterback throw, where the index finger is the last digit to touch the football (Fracas & Marino, 1989). These two torques cause clockwise rotation of the ball (when viewed from in front of the long snapper), and their resultant can be demonstrated with the angular impulse-momentum relationship. Recall that $T \bullet t = I\omega_{final} - I\omega_{initial}$ where T is the sum of the torques acting on the ball, which in this case are the right and left hands imparting spin to the ball about its longitudinal axis.

Follow through

During the follow through, both hands are thrust backward between the legs toward the punter (Figure 1.8.). The fingers are spread, and the palms are turned to face outward from the midline (pronated) after the snap (Fracas and Marino, 1989). Once the snap is made, the angular velocity of the body segments decreases as they begin to negatively accelerate, or decelerate. The negative acceleration of the joints is a result of arm/leg contact, eccentric contractions of antagonistic muscles, elastic components of antagonistic muscles (Ohton, 1988) to the muscles of force production, and the joints simply reaching their terminal ranges of motion.

Figure 1.8: Follow through phase of the long snap (front view and sagittal views).

Eccentric muscle contractions occur when the load pulls a muscle to a longer length despite opposing forces being generated by the active cross-bridges (Vander, 1994). This may occur after release as the antagonistic muscles (muscles opposing the contractions made during the snap) contract eccentrically to slow the limb segments. It may also be possible that the segments involved move through their complete range of motion, which results in a combination of negative acceleration and terminal range of the movement. This is likely occurring at the elbows as they extend and the forearms as they pronate. It is most likely that a combination of eccentric contraction and terminal range of motion cause the end of motion in bilateral elbow extension, shoulder medial rotation, and forearm pronation during the long snap.

Definition of terms

Ability: A general trait or capacity of an individual that is a determinant of a person's achievement potential for the performance of specific skills (Magill, 2001).

Acceleration (a): The rate at which velocity changes with respect to time (Hay, 1993).

$a = (v_{final} - v_{initial})/t$: where a = average acceleration; v_{final} = final velocity, $v_{initial}$ = initial velocity, and t = time.

Anatomical Reference Position: Erect standing position with the feet slightly separated and the arms hanging relaxed at the sides, including the palms of the hands facing forward; considered the starting position for body segments (Hall, 2007).

Angular acceleration (α): The rate of change in angular velocity (Hay, 1993).

$\alpha = (\omega_{final} - \omega_{initial})/t$: where α = angular acceleration, ω_{final} = final angular velocity, $\omega_{initial}$ = initial angular velocity, and t = time

Angular impulse: Product of torque and the time interval over which the torque acts. An angular impulse results in a change of angular momentum (Hall, 2007).

$J = T \cdot t$; where J = Angular impulse, T = torque, and t = time

Angular momentum: Quantity of angular motion possessed by a body; measured as the product of moment of inertia and angular velocity (Hall, 2007).

$H = I \cdot \omega$; if H = angular momentum, I = moment of inertia, ω = angular velocity

Angular velocity (ω): Rate of change in angular position or orientation of a line segment (Hall, 2007). $\omega = \theta/t$; where ω = angular velocity, θ = angular displacement, t = time.

Attentional focus: The process used to selectively attend to specific environmental information (Coker, 2004).

Axis of rotation: Imaginary line perpendicular to the plane of rotation and passing through the centre of rotation (Hall, 2007).

Balance: A state of equilibrium or the ability to control equilibrium (Hall, 2007).

Base of support (BOS): Area bound by the outermost regions of contact between a body and support surface or surfaces (Hall, 2007); this includes the area between contact points if more than one is present.

Biomechanics: Application of mechanical principles to living organisms (Hall, 2007).

Centre of mass (centre of gravity): Point around which the mass and weight of a body are balanced, no matter how the body is positioned (Hall, 2007).

Concentric contraction: A situation where muscle fibers shorten and therefore move a load; the muscle tension must become and remain slightly greater than the opposing load to be a concentric (or shortening) contraction (Vander, 1994).

Down: A unit of game action. A team has (three) opportunities to run a play from the line of scrimmage in an attempt to travel ten yards. When a team has succeeded in moving the football ten yards or more on any given down, it is said to have made a first down. It then has (three) more chances to make another first down or score a touchdown (DeLuca, 1978).

Eccentric contraction: The contraction as a load pulls a muscle to a longer length despite opposing forces generated by the active cross-bridges is called an eccentric (or lengthening) contraction (Vander, 1994).

Field goal: A kick resulting from a play from scrimmage which travels over the cross bar and between the uprights. The ball must be either place kicked or drop kicked. The offensive team receives three points (DeLuca, 1978).

Force (F): The pushing or pulling action of one body on another that causes a change in the state of either body being "at rest" or "in motion" is termed a force (Hay, 1993).

Horizontal Velocity (V_h): Change in horizontal displacement with respect to time; or velocity in the horizontal direction (Hall, 2007).

Impulse: Product of force and the time interval over which the force acts (Hall, 2007).

$I = F \cdot t$; where I = impulse, F = force, and t = time

Impulse-momentum relationship: When an impulse acts on a system, the result is a change in the system's total momentum (Hall, 2007).

$F \cdot t = m \cdot v_{final} - m \cdot v_{initial}$; if F = force applied, t = time, m = mass, v = velocity.

Inertia: Tendency of a body to resist a change in its state of motion (Nordin & Frankel, 2001).

Kinematics: The description of motion, including the form, pattern or sequencing of movement with respect to time (Hall, 2007).

Line of gravity: A vertical line extending through an object's centre of mass.

Line of scrimmage: An imaginary line, extending from sideline to sideline, parallel to the goal line, and passing through the point of the ball farthest from Team A's Goal Line (CFL rules of play, 2008).

Linear momentum (M): The quantity of motion possessed by an object (Enoka, 2002).

$M = m \cdot v$; if M = momentum, m = mass, v = velocity

Long snap: The initiation of the play by the centre when the centre passes the ball between his legs to the holder or the punter (DeLuca, 1978).

Moment arm: Shortest (perpendicular) distance between a force's line of action and an axis of rotation (Hall, 2007).

Moment of inertia: Inertial property for rotating bodies representing resistance to angular acceleration; based on both mass and the distance the mass is distributed from the axis of rotation (Nordin & Frankel, 2001).

$I = mk^2$; where I = moment of inertia, m = mass, and k = radius of gyration

Punt: The act of kicking the ball over to the defending team, usually in a fourth down situation when a team does not have a good chance at a first down and is too far away to try for a field goal (DeLuca, 1978).

Range of Motion (ROM): The angular displacement about a joint (Enoka, 2002).

Segmental rotation: When individual segments rotate in a sequence (usually from largest to smallest) as opposed to all joints rotating at once (block rotation). (Alexander, 2002).

Skill: A task for which the primary determinant of success is the quality of the movement that the performer produces (Schmidt & Wrisberg, 2008).

Snap: The initiation of the play by the centre when he passes the ball between his legs into the hands of the quarterback (DeLuca, 1978).

Special teams (also called **Suicide Squads):** All of the kicking teams including: the kick-off team, kick-off return team, punt team, punt return team, and place kick team. They are called suicide squads because of the high incidence of injuries to those assigned to the special teams (DeLuca, 1978).

Stretch reflex: A monosynaptic reflex, mediated by muscle-spindle stretch receptor, in which muscle stretch causes contraction of that muscle (Vander, 1994).

Vertical velocity (V_v): Change in vertical displacement with respect to time; or velocity in a vertical direction (Hall, 2007).

Chapter 2

Review of literature

Introduction

Chapter two will provide a review of literature on the distance snap, as well as applications of relevant biomechanical concepts to the skill. Beginning with a thorough description of each phase of the skill, the reported variables that have been measured in successful snaps will also be discussed. The phases will be consistent with the brief description of the skill, as well as their associated sub-phases, introduced in the previous chapter, including: preliminary movements or setup (stance and grip), backswing, force producing movements, critical instant (including airborne phase), and follow through. To conclude the chapter, applications of biomechanics to the centre's long snap will be discussed and demonstrated with sample calculations.

Background

The centre's long snap to punter is certainly unique in sport. Besides the apparent novelty of the skill, there are many associated reasons to study the skill. The lack of available research is remarkable, with few studies available on the topic. This limits the current understanding of the skill, and often results in coaches being unable to explain certain instructional aspects of the long snap. When this occurs, the instruction tends to be more mythological in nature, as opposed to technical or biomechanical.

The lack of research also makes the analysis of the skill more difficult, since kinematic variable values for differing skill levels are not readily available to aid in comparison. Long snap skill analysis has other potential challenges besides limited past studies. Rotational values are often difficult to measure in ideal situations; and even more difficult in the analysis of the long snap. Since the shoulders are not completely fixed while the shoulder medial rotation and forearm pronation occur, the plane and axis of rotation for the upper and lower arm are constantly changing. Fixed camera angles make it difficult to establish a longitudinal point of reference from which to measure the rotation.

The relative difficulty of teaching, learning, and performing the skill presents another argument for expanding the current knowledge of the centre's long snap to punter. Since the skill takes less than a 3 tenths of a second to execute (Blegen et al, 2005), it is difficult to observe or suggest adjustments to technique using only the naked eye. The coach's most useful tool is often the total snap time and the result of the snap. By timing the movement, and observing accuracy, a coach can infer potential alterations to the movement. Ideally, these inferences should be based on observed results. By conducting a detailed video analysis, the movement can be observed in frames of $1/60^{th}$ of a second. This frame by frame analysis provides the visual information necessary to make definitive statements about long snapping technique, and may prove beneficial in predicting which variables contribute to snapping success during the different phases of the skill.

The awkward position of the body also contributes to the difficulty of performing the long snap. The athlete's upper body is not only positioned upside down which will alter their spatial perception, but the desired target must also be viewed upside down relative to the long snapper's perspective. The football must be thrown backwards in a very short time frame, allowing for few adjustments to the sequence or timing of the movements during skill performance.

Finally, rotation of the trunk and hips is removed from the skill making it much more difficult to generate force. Unlike other more upright throwing skills (such as the one handed overhead quarterback pass), the head is tucked down between the legs and both hands are used to snap the football. Without the trunk or hip rotation during the throw, the long snapper can only generate force in the direction of the throw with trunk flexion, shoulder extension, elbow extension, and wrist flexion. This means fewer muscles must be used to generate maximal forces, making the skill more difficult.

Preliminary movements

Stance

Prior to the long snap, the ball is placed on the ground at the line of scrimmage by the official before any player is allowed to touch it. Once the centre approaches the line of scrimmage, he will assume his stance for the snap. At the commencement of a scrimmage play, "one Team A player (the Centre) shall take position facing the opponent's Goal Line with the ball on the playing surface immediately in front" (CFL rules of play, 2008). The long snapper should assume a stance that is wider than shoulder width apart. The ball is perpendicular to the line of scrimmage (pointed forwards and backwards) with the middle of the ball bisecting the centre's body (Figure 2.1) (Grindle, 1999). The athlete's toes should be 0.30 to 0.50 m behind the nearest tip of the football (Catapano, 1998).

Figure 2.1: Parallel stance wider than shoulder width with the football bisecting the body.

Both feet should be nearly perpendicular to the line of scrimmage, although some snappers will assume a position with the toes pointed slightly outward. This out-turn of the toes, which can be attributed mainly to lateral rotation of the hip joint (and somewhat to lateral rotation of the tibio-femoral joint which is possible in a flexed knee), may put some individuals in an anatomical position which allows for further flexion of the hips. By further flexing the hips, the athlete can lower his buttocks (and therefore his centre of gravity) to improve balance and stability. This lower position may also increase the force potential of the limbs associated with the flexed joints during the force production phase of the skill by increasing the range of motion through which they can generate force.

A common variation of the stance is the parallel or non-parallel positioning of the feet. This is referring to the line made across the toes, and whether or not that line is parallel to the line of scrimmage. In the parallel stance (Figure 2.1.), the feet are directly beside each other in a wider than shoulder width stance. If a line was drawn along the line of scrimmage, and another line was drawn across the front of the athlete's toes, these lines would be nearly parallel to each other. This stance tends to be preferred for the snap to punter because of the longer distance of the snap (12.8 m) when compared to the snap to holder which is required when attempting a field goal or place kick (6.4 m). With a greater distance for the football to cover, even small lateral (side to side) deviations in release may result in an errant snap attempt, making it more difficult for the punter to catch. The parallel stance also offers the advantage of not exposing the oncoming direction of push-off for blocking assignments. This helps to keep the defensive player guessing as long as possible as to which direction the centre will move after the snap (Zauner, 1985). A disadvantage of the parallel stance is that after snapping the ball, the centre will likely step back with the foot on the opposite side of desired motion, so that he can push-off in the direction of blocking assignment, which takes time and allows the defense more time to penetrate into the backfield.

In the non-parallel or staggered stance, the snapper may stand toe-instep or toe-heel. In other words, the line of scrimmage and the line made across the toes of the snapper are not parallel to each other. The non-parallel stance may benefit the snapper if he has to snap away from a direction of rushing opponents (Ohton, 1988), or if a quick lateral motion to a blocking assignment is required. It is less common to see the non-parallel stance in a centre snapping to the punter, where release accuracy is vital due to a greater distance covered by the football. It is more common to see the non-parallel variation in the distance snap to the holder for field goal (half the distance at 6.4 m) since a ball that is not perfectly released will not deviate as much. The non-parallel stance may also be present in the distance snap to the quarterback in the shotgun formation (1.5–3.5 m); where the centre may stagger his stance in order to get a quicker start in a known direction of movement after completion of the snap. In this situation, where the ball is released with considerably less velocity to a much closer target, errors in accuracy are less noticeable. A possible recommendation for further study is whether some long snappers incorporate both parallel and non-parallel stance preference depending on the circumstances.

Grip

Once the centre has established his stance, he can grip the ball. The snapper should not pick up the ball from the ground to establish the grip. The player is allowed one slight adjustment of the ball while it is in contact with the ground (Canadian Football League, 2008); though this rule is rarely enforced when more than one slight adjustment occurs, unless a clear delay of game is occurring. The centre, once assuming the final stance, must remain motionless until the snap and is permitted to look back once between his legs for aiming (CFL rules of play, 2008).

Gripping the football in the long snapper's stance can incorporate: the dominant hand grip, the symmetrical grip, or the one-handed grip (Ohton, 1988). It is rare in the modern game to see anything but the dominant hand grip (Gammon, 2000) regardless of the distance or direction required for the snap. Although the symmetrical (Figure 2.6) or one-handed (Figure 2.7) grips are used by some individuals for the shorter distance snaps or in rare instances, the majority of athletes at all levels will use the dominant hand grip (or a slight variation of it). This is supported by the dominant hand grip being the only method cited in various articles (Blegen et al, 2005, Grindle, 1999, Fracas & Marino, 1989)

<u>Dominant hand</u>

The dominant hand grip incorporates the right hand as the primary or "throwing" hand, and the left hand as the secondary or "guide" hand. The dominant hand grip is established in the same way a quarterback grips the ball. The throwing hand is defined as the last to touch the football through release, which for this discussion is the right hand, and the left hand is referred to as the guide hand.

The index finger is placed at the top of the laces, the thumb wraps around the ball, and the other three fingers rest along the laces (Catapano, 1988), with some variation among individuals when it comes to specific finger placement on the laces. The thumb and index finger should form a 'U' when viewed from the front of the ball, with both fingertips being equal distance from the end of the ball (Figure 2.2). Each athlete will differ slightly in their right hand grip of the football for the long snap due to hand size, hand strength, prior instruction, or comfort.

Figure 2.2: Right hand position for the dominant hand grip (front and side views).

The long snapper must determine the most comfortable and effective grip; which is often related to the size and strength of the hands. With larger hand sizes, athletes tend to grip the ball closer to the centre, which places more of the fingers on more of the laces. Smaller hand sizes relate to the athletes bringing the thumb, or index finger forward, closer to the end of the football where the circumference is less. The fingers are spread to create areas of frictional contact for maximum applied torque. Friction is independent of surface area, or a greater contact area does not generate more friction (Hall, 2007), but the spread position of the fingers may allow the force to be applied more evenly to the outside of the football. This may help to prevent slippage of the ball during the throwing motion, and allows the (athlete) to apply (a greater) torque to the ball, creating a spiral (Fracas & Marino, 1989).

Once the centre has established the right hand grip, the ball is placed on the ground with the laces down. The right hand tends to “cup” the ball, with the fingers on the laces; this action is creating by flexing the wrist from anatomical position. Figure 2.3 shows the position of the right hand during the backswing phase of the long snap.

Figure 2.3: Primary, or throwing hand, placement for the long snap to punter.

The guide hand is then placed on the ball, and should be placed on the top of the ball in a wide spread position with the top seam under either the index or middle finger (Grindle, 1999) (Figure 2.4). Although individuality is inevitable when observing different grips, certain instructional points tend to surface consistently regardless of source. A coaching manual (Zauner, 1985) for potential long snappers instructs them to imagine making the letter T on the ball with the thumb of the right hand and the index or middle finger of the left hand. The vertical line of the letter T is made by the index or middle finger of the left hand; and the horizontal line of the letter T is made by the thumb of the right hand (L. Orris, personal communication, September 14, 2008). By placing the hands on the ball identically each time the ball is snapped, the athlete has a better chance of replicating successful performances. What defines a successful performance can only be determined by identifying the joint kinematics of the body through all phases of movement.

Figure 2.4: Secondary or "guide" hand placement for the centre's snap to punter.

This description is a guideline created from the literature and personal observation. This researcher has observed many different variations in the placement of "throwing" hand, as well as the "guide" hand placement (Figure 2.5). The guide hand may be placed anywhere along the long axis of the ball; or perhaps the index or middle finger will be placed directly on the seam instead of the seam dividing them. With so many variations having been observed, it is apparent that no single method is ideal for all athletes to adopt, and individual modifications are remarkable.

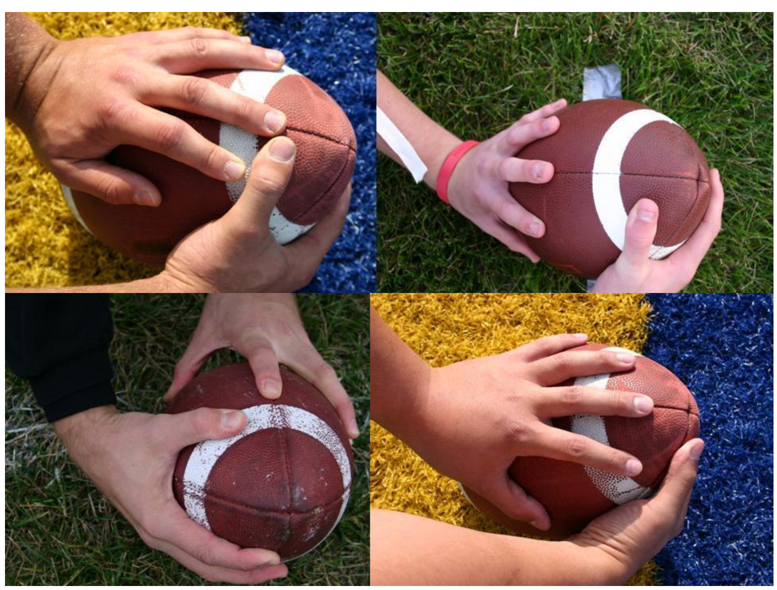


Figure 2.5: Variations of hand placement observed with the dominant hand grip.

Symmetrical

The second technique, when it comes to gripping the football for the distance snap, is a symmetrical, or nearly symmetrical grip; where the right and left hands grip opposite quarters of the front half of the football. Ohton (1988) suggests that this technique "should be experimented with if the snapper has excellent grip strength and good snapping experience". The symmetrical grip, though usually resulting in a skilled snapper able to achieve higher ball velocities, may result in less accuracy. If both hands do not release the ball at the same time, the long snapper may have a more difficult time in keeping the flight of the ball straight. Velocity, though important, should be not be achieved by sacrificing accuracy. In fact, it could be argued that accuracy is paramount because without it the snap is quite ineffective; and that velocity may have to be compromised for accuracy (Ohton, 1988 & Harrington, 2003). This author agrees that this is true at the novice level, but as skill level increases, velocity and accuracy become equally paramount. The symmetrical grip (Figure 2.6) may be a technique that the experienced snapper would experiment with, but due to the likelihood of reduced accuracy, should not be introduced as the grip of choice to a novice snapper (at any level).

Figure 2.6: Hand placement for the symmetrical long snap grip (front and top view).

<u>One-handed</u>

A final possibility to consider in the grip is that the snapper takes the football with only the dominant hand, while the left hand remains off the ball (Figure 2.7). The strictly one-handed method is often used in the "shotgun" formation snap to the quarterback, where the ball must only travel 1.5 to 3.5 m, and is simply popped up in the air for the quarterback to catch. The "shotgun" is a passing formation that allows the quarterback more time to scan the defense and find a defender (DeLuca, 1978). Since the two players are relatively close to each other in this formation, a two-handed, high velocity snap would likely result in a fumbled exchange of the football. By removing the left hand, the ball not only releases with less velocity which makes it easier to catch; but the centre now has a free hand to block with much sooner, as it is not involved in the phases of the skill.

Figure 2.7: Hand placement for the one-handed long snap grip (front and top view).

Individual long snappers may choose the one-handed grip for the snap to holder in the field goal or place kicking situation. This may occur less often in the field goal or place kick situation than the "shotgun" formation since the ball must now travel 6.4 meters in less than one second to allow time for the kick. The necessary velocity is such that it seems likely the athlete will choose to incorporate the second hand. From a biomechanical perspective, it does seem likely that the two-handed snap is faster than the one-handed snap. The increase in the torque available when two hands are used to accelerate the ball about the axis through the shoulders is discussed by Hay (1993) as "almost certainly being greater than the increase in the moment of inertia of the rotating system (arms-plus-ball) that tends to offset it" (provided the range of motion at the shoulder(s) is similar for both methods). As the distance between snapper and receiver increases, velocity becomes of greater importance. As velocity becomes of greater importance, the need for both hands to apply force becomes more apparent. This will provide the most significant reason for likely eliminating the one-handed technique as the preferred method for the snap to punter (12.8 m).

Backswing

Backswing is the phase that puts the athlete in position to generate force for the skill, in this case the delivery of the football. The backswing phase of the distance snap is unique, in that it is held for some time before force production begins. The snapper only wants backward movement of the football once the sequence has begun. Any upward or forward movement of the football would negatively affect performance, since one of the main success factors of the long snap is to keep the total snap time (TST) as short as possible. This means the force producing muscles are placed on a slight stretch, then held in that position awaiting the signal for action. Unlike most throwing motions, the long snap cannot rely on the backswing to elicit a stretch reflex for maximal force production, other than at the elbow joints which is discussed in Chapter 5. This "stretch reflex" is a monosynaptic reflex initiated by stretching the muscle spindles and resulting in the immediate development of tension within the muscle (Nordin & Frankel, 2001). Although some elastic contribution of the stretched muscle will exist in the long snap since the muscles are indeed on a stretch; the large eccentric contraction is not present since the muscles are held in that position of stretch. In fact, the muscles involved are asked to hold an isometric contraction prior to concentric contraction since the centre must be ready to snap while awaiting the signal. The downside of this is that if the athlete is asked to hold the isometric contraction for too long, then fatigue may become a factor, decreasing potential force production.

With the football in position for the long snap, the athlete is in a balanced and stable position with the weight of the body balanced over the feet. There should be very little or no weight on the ball itself (Blegen et al, 2005). The hips and knees are flexed to simulate an athletic “ready” position. “The centre’s stance (backswing) should be consistent and comfortable” (Zauner, 1985). The trunk is flexed forward, and tilted slightly down from an imaginary horizontal line. The snapper should be far enough back from the line of scrimmage that when placing the ball in front of the body, a large range of shoulder flexion and elbow extension is necessary in order to place the ball on the line (Figure 2.8).

Figure 2.8: Demonstration of an athlete in the backswing position of the long snap.

When discussing the one-hand overhead quarterback throw, Tarbell (1970) states that an excessive forward lean will limit the range of motion through which motion can occur. The same is true in the long snap, where excessive forward lean (or excessive downward deviation from an imaginary horizontal line) will limit the athlete's range of motion through which force can be applied to the ball. This would be partly limited by the contact of the upper body against the lower body when the additional protective equipment (shoulder pads) is considered which may also limit shoulder extension. Figure 2.8 also demonstrates the nearly horizontal position of the trunk identified by Blegen et al (2005) which allows for the greatest range of motion at the shoulder during the force production phase. A more horizontal trunk position also may mean the long snapper can get into a blocking stance much faster. This would likely make him more effective in stopping the defensive rush once the snap has been completed.

Blegen et al (2005) found that shoulder flexion angles (135 ± 6.33° vs. 98 ± 9.01°) and elbow extension angles (133 ± 8.1° vs. 95 ± 6.77°) were both significantly greater in the set (backswing) position for university level snappers when compared with scholastic (high school) long snappers. This study will refer to degrees of elbow flexion instead of elbow extension to be consistent in measuring angular deviation from anatomical position. If the lower arm were fully extended in relation to the upper arm, the measure of elbow flexion angle would be 0° or in neutral anatomical position. For an illustrative example, Figure 2.9A shows 120.3° of elbow extension (inside angle of upper arm to lower arm), instead being labelled as 59.7° of elbow flexion (angle from extended line of the humerus to the lower arm which) which will be consistent with the current study and can be seen in Figure 2.9B.

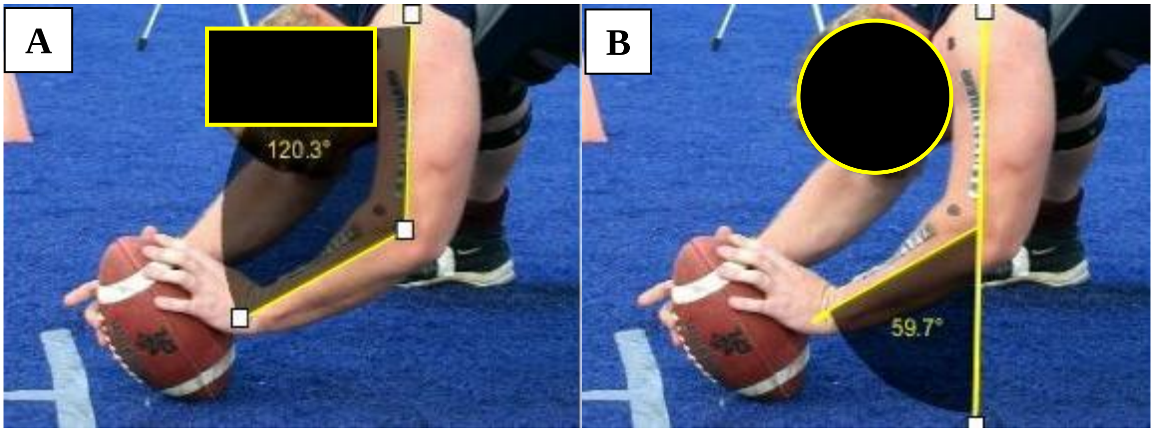


Figure 2.9: Sample angles showing how 120.3° of elbow extension (A) will instead be described as 59.7° of elbow flexion (B).

Proper limb placement in the backswing or set position was found to be significantly related to a reduction in total snap time (Blegen et al, 2005). By increasing shoulder flexion and elbow extension, the college snappers lengthened the distance through which force could be applied to the ball during the preflight (force production) phase, thus, increasing the takeoff velocity of the ball. The same study found no significant differences between the two skill levels for hip flexion in the set (backswing) position. It seems clear that more skilled long snappers will place the ball out in front of their head, as opposed to under their face or forehead. This is done by keeping the trunk nearer to the horizontal and by flexing the shoulders while maintaining extension or limited flexion at the elbows.

When the ball is placed on the line of scrimmage, the centre will tilt the front (nose) of the football off the ground. Henrici (1967) does not report the angle of tilt, while Zauner (1985) and Gammon (2000) quantify the angle between 30 and 45° (from the horizontal). The tilt of the ball is the angle measured by the intersection of a line parallel with the ground and a line drawn through the longitudinal centre of the ball (Figure 2.10).

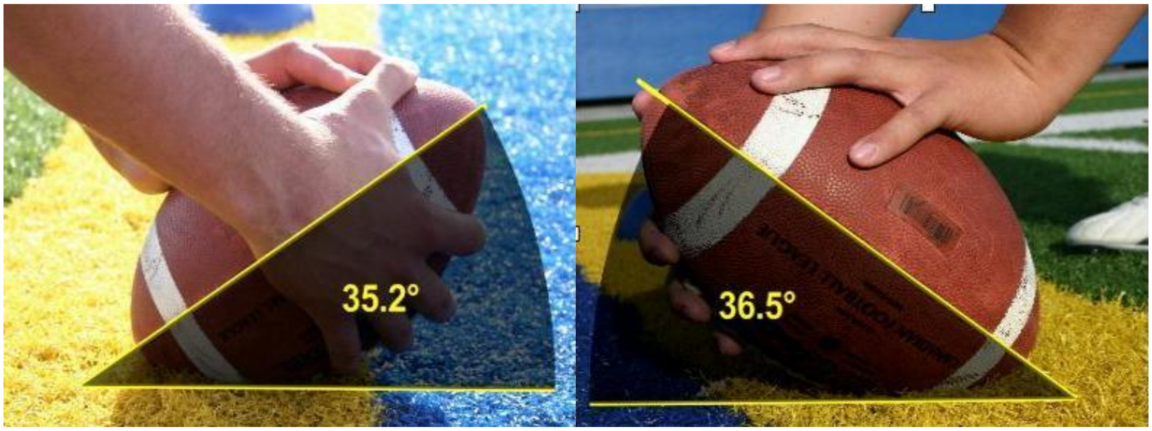


Figure 2.10: The ball tilt (angle) of the football relative to ground in the long snap.

With slight variations apparent, the tilt allows the fingertips to be placed under the ball (wrist flexion) to allow for a longer time of force application during the right hand throwing motion. The tilt will also place more of the guide hand comfortably on the football; as well as placing the left wrist in an extended, pre-loaded position for a greater range of motion through force production.

Prior to the snap, the centre in the kicking formation is permitted to move the head for the purpose of checking an opponent's position prior to snapping the ball (Canadian Football League, 2008). Once the backswing position is "set", the long snapper must hold that position with little or no movement. If any offensive player moves prior to the snap in an effort to draw the defensive players offside, they can be penalized. With direct reference to the centre, the rules of play state that Team A is subject to a penalty for attempting to draw an opponent offside if:

(a) the centre fakes a snap, without snapping the ball or,

(b) the centre, having assumed a stance holding the ball, bobs the head, moves the shoulders or flexes the knees without snapping the ball.

During the backswing position, the muscles associated with hip and knee extension must contract isometrically to hold the athlete in a stationary position. At the hip, gluteus maximus is mainly responsible for hip extension (especially from a flexed position) (Moore, Dalley, & Agur, 2010), and therefore primarily responsible for holding the hip in a flexed position against gravity. With the hips being held isometrically in a partially abducted position, hip adductors (adductor magnus, adductor longus, and gracilis) and hip abductors (gluteus medius and gluteus minimus) are assisting to hold the hip in position against gravity, as well as assisting to stabilize the hip joint in the backswing. At the knee, the quadriceps group of extensors (vastus medialis, vastus intermedius, vastus lateralis, rectus femoris) is primarily responsible for holding the backswing position in the ready or pre-load position.

Force producing movements

Along with accuracy of delivery, the primary goal of the centre's snap to punter is to achieve maximal velocity of the ball. This goal is achieved only with a smooth transfer of momentum and the summation of forces through the body segments involved. The summation of joint forces refers to force of the larger, proximal body segments initiating the movement, and progressing to the smaller, more distal segments. This transfer should be very smooth and rapid as each body part transfers its forces to the next (Yessis, 1985). The summation of joint forces during the force producing movements is imperative in creating the desired effect in any skill. The muscles have to apply force in the correct amount, over the correct range and time period, and in the correct sequence (Carr, 1997). This long snap is an excellent example of this due to the short release time necessary.

The actual performance of the snap involves a powerful (bilateral) arm swing in one continuous motion; with the elbows swinging directly back through the legs of the centre (Catapano, 1988). The hips and knees extend, while the position of the ankles shifts from dorsiflexion toward plantarflexion (Ohton, 1988). The spinal column (trunk) flexes forward, though does not appear to cover a large range of motion. Instead the extension of the knees raises the hip ands tips the entire system down. It will be interesting to measure the changes in hip and trunk flexion during the long snap. While the hips are going up, the shoulders and head tip down, and the glenohumeral joint extends and adducts slightly causing the rearward motion of the arms (Ohton, 1988). The elbows first flex then extend as the forearms (proximal and distal radioulnar joints) pronate, and the wrists flex as force is imparted to the ball until release. The "cupped" right hand present in the dominant hand grip allows the wrist segment to move through a larger range of motion thereby increasing the time of force application to the ball.

The centre should be trying to, in one fluid motion, bring the ball backward and upward forcefully between his legs (Grindle, 1999) (Figure 2.11). These movements will allow the centre to achieve the objective of getting the ball to the punter as quickly and accurately as possible. The difference between a successful or blocked punt can be measured in hundredths of a second. Professional players are rarely considered for the position if their total snap time (the time it takes from first movement of the long snapper to the reception by the punter) exceeds 1.2 seconds. In order to give the punter the time necessary to execute the punt, the centre's long snap to punter must be performed with speed, fluidity and precision. The only thing expected from a long snapper is the exact same delivery every single time regardless of defenders or wind (Gammon, 2000).

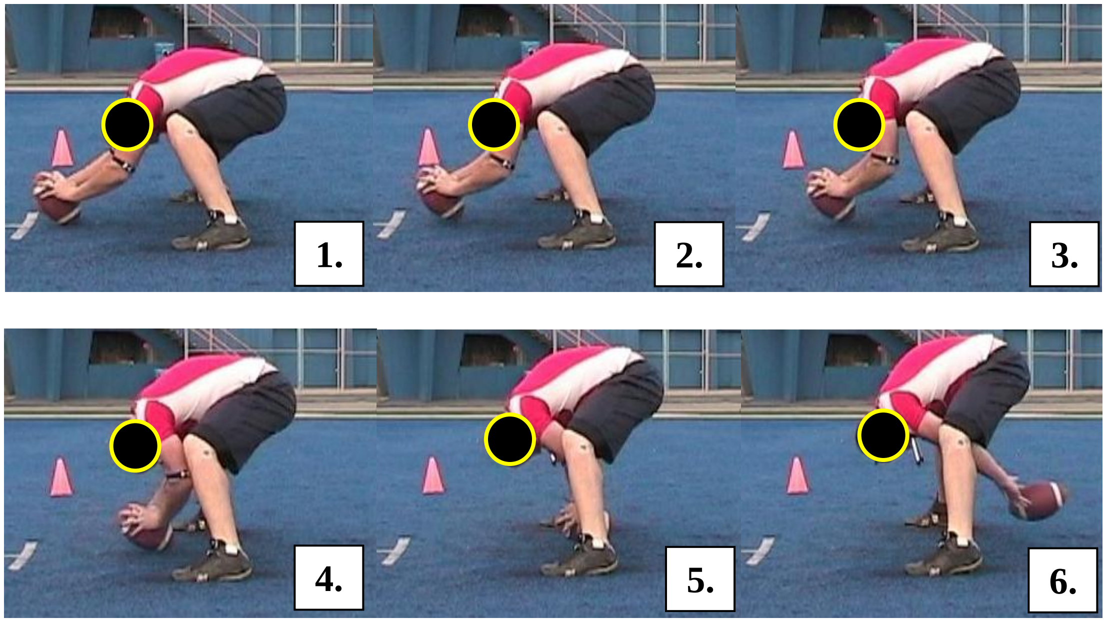


Figure 2.11: Sequential images of the force production phase for the long snap to punter.

Few studies have quantified angular velocities of the limb segments in the long snap, though Henrici (1967) attempted to calculate relative contribution of each limb to the snapping motion, given as a percentage, by estimating angular velocities. Eight segments were studied: foot, shank, thigh, low back, upper back, brachium, forearm, wrist and hand. Henrici determined the shoulder contributed 28.3%, the elbow contributed 32.08%, and the wrist contributed 32.79% to the linear velocity of the football; while the trunk and lower extremities only contributed 6.82%. Analytical vector calculations were used to calculate the segmental contributions to linear velocity of the football.

Blegen et al (2005) only looked at shoulder flexion and elbow extension in the set position, and did not calculate their respective angular velocities through the snapping motion. The hip flexion of the athletes in the study was calculated in both the set position and the release position, though velocity calculations were not completed. It was interesting to note in Blegen's study that there was no difference between the high school and university athlete in hip flexion in the set position, but the hip flexion angle at ball release was significantly less (23%) among the university snappers. This means the university snapper tended to keep the trunk more horizontal by reducing the height of the hips and reducing the amount of hip flexion and forward trunk flexion, thereby reducing hip flexion angles. It also supports the instruction snappers are given to "reach" back for the punter (Fracas & Marino, 1989) as they project the ball, and to keep the arms from going above the knees at and through release. This "reaching" back motion, which keeps the arms from drifting up, may be easier to accomplish with a more horizontal positioning of the trunk and less hip flexion. If this is true, then the position of the trunk may be useful in helping to identify the level of skill in the athlete being observed.

The position of the head and neck differs from player to player, and team to team through the various leagues and levels. All long snappers will look back between the legs before the snap for aiming purposes; but whether or not they keep the head down through the snap is another discussion. The duties of the centre are: to perform a good snap, block in the assigned direction, and cover the punt downfield (Zauner, 1985). Differing blocking schemes may have the guards (players on either side of the centre) assume the head-on blocking assignments, which will allow the snapper to temporarily ignore any blocking assignments until completion of the snap. This method allows the centre to keep the head down for the duration of the movement. Other playbooks may call for the centre to block a defensive player immediately, meaning the centre should keep the head up during the snap to avoid injury to the upper back and neck. This author's study will not measure neck flexion or head position, and will not ask the subjects to choose one method over the other; but instead to execute the skill with whichever method they are more comfortable with.

As for which method provides better results, Rubicam (1965) and Slebos (1968) looked at the visual (keeping the head down) and non-visual (keeping the head up) methods and their relationship to accuracy and ball velocity. Rubicam (1965) conducted a study to determine whether flight time and accuracy differed between the two methods and was unable to find any significant difference between the visual and non-visual methods. Slebos (1968), unsatisfied with the results, conducted a similar study and found no significant difference in flight times, but found the visual method significantly improved accuracy.

During the force producing movements, hip extension is primarily achieved by gluteus maximus. This largest and most superficial gluteal muscle forms a covering over the ischial tuberosity (Moore et al, 2010). Hip extension is also assisted by the hamstring group of muscles (biceps femoris, semitendinosus, and semimembranosus) which cross the posterior hip from their common point of origin (ischial tuberosity). Knee extension is primarily achieved by the quadriceps group of muscles on the anterior thigh. These muscles include: rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis. Plantarflexion is primarily achieved by the plantarflexor group of muscles located in the posterior compartment of the lower leg (Ohton, 1988). These muscles, in order of contribution to force, include gastrocnemius, soleus, and plantaris (which provides minimal contribution). Plantarflexion is also assisted by the muscles passing posterior to the medial malleolus of the tibia, then inserting on the base of the foot. These are tibialis posterior, flexor digitorum longus, and flexor hallucis longus.

The trunk appears to flex further forward as the lower body completes its extension. These movements occur at nearly the same time, and seem to act in opposition to each other. Trunk flexion is primarily achieved by the rectus abdominus muscles, with some assistance from the external and internal obliques when the pelvis is stable. Trunk flexion is important because of the large muscles involved in the movement and their contribution to the summation of joint forces. The summation of joint forces refers to contracting muscles in order, from largest or slowest, to smallest and fastest to achieve maximum velocity of the object being thrown. The long snapper should not flex the trunk through too large a large range of motion, in order to allow maximum range of motion of the shoulders.

The shoulders then begin to forcefully extend and internally (medially) rotate. Shoulder extension is primarily achieved by latissimus dorsi, teres major, and the posterior fibers of the deltoid muscle group. Because of the high degree of shoulder flexion in the backswing, pectoralis major will also contribute to the initial extension of the shoulders with its insertion on the lateral lip of the bicipital groove of the humerus (Moore et al, 2010). The medial rotation of the humerus at the shoulder is primarily achieved by subscapularis, latissimus dorsi, and teres major; with the sternal head of pectoralis major assisting in the rotation.

While the shoulders extend and medially rotate, the elbows will forcefully extend, the forearms will pronate, and the wrists will flex and adduct. The primary muscles of elbow extension are the triceps brachii group, with assistance from anconeus. Pronation is the action of forearm internal rotation and occurs specifically at the proximal and distal radio-ulnar joints. Primary muscles of pronation include pronator teres and pronator quadratus. The wrists are also forcefully flexed near the end of the force production phase and through the critical instant (release). The initial backswing position of “cupping” the right wrist allows the wrist segment to move through a larger range of motion thereby increasing the velocity of the ball (Fracas & Marino, 1989). Wrist flexion is primarily achieved by the muscles located in the anterior compartment of the forearm. In order of contribution to force production, these include: flexor carpi radialis, palmaris longus, and flexor carpi ulnaris (Ohton, 1988). Flexor digitorum superficialis and flexor digitorum profundus will also assist in wrist flexion.

Airborne phase

As a sub-phase that occurs between force production and critical instant, the airborne phase is more pronounced as the athlete's strength and skill improve. Its presence may be a significant indicator of more advanced snappers. In the original study by Henrici (1967), there was no discussion of the athlete moving backward during the snap. Henrici defined three events of the skill only: start (comparable to the backswing position), prior to release (an undefined time during the force production phase), and release (critical instant).

Rubicam (1965) and Slebos (1968) were more concerned with the relationship of snapping success to chosen stance (parallel or non-parallel) and visual method (visual or non-visual); and also neglected to include any discussion of an airborne phase. Ohton's (1988) kinesiological analysis involved four distinct phases: stance (phase 1), acceleration (phase 2), release and deceleration (phase 3), and contact position (phase 4). Although neglecting to make reference to, or discuss, an airborne phase, Ohton included figures in his investigation which did show the feet sliding backward slightly between phase 2 (acceleration) and phase 3 (release and deceleration).

Grindle (1999) discusses the procedure of the long snap in a high school coaching manual, and though brief, acknowledges the airborne phase. Grindle states that "as the ball is released the centre should have, by the backward force of the snap, a slight sliding of the feet backwards". The reason given is to keep the long snapper from raising his buttocks, or to keep the hips and buttocks pointed more at the punter as opposed to up in the air, which tends to help avoid high snaps over the punter's head.

Harrington (2003) conducted a study to further Rubicam (1965) and Slebos' (1968) work, and had long snappers performing snaps in which the guide hand, foot position, and visual method were randomized to analyze their effect on success rates. Variables at release of the football were analyzed, though no discussion of the feet or body sliding backward was mentioned.

Qualitative analysis (Zauner, 1985) has revealed that more successful long snappers seem to glide back toward the punter throughout the motion of the snap, but prior to the investigation of Blegen et al (2005), no quantitative measures have been attempted. These authors initially investigated the long snap in the set (backswing) position, the mid-point of the motion (force production), and release (critical instant). In their discussion, they further broke down the snap into three distinct phases: set position, pre-flight, and flight. "The flight phase is a direct result of actions taking place during the set position and pre-flight phases" (Blegen et al, 2005). Blegen et al analyzed the movement of the centre of mass in the anterior/posterior direction (ΔCM_{ap}), and the superior/inferior direction (ΔCM_{si}). The ΔCM_{ap} and ΔCM_{si} were both significantly higher in the university long snappers when compared to high school snappers. "This aids in further lengthening the distance in which force is applied to the ball, and also allows the university snappers to add their body's momentum to the ball" (Blegen et al, 2005). This is a true, but generalized statement, and needs to be discussed in more biomechanical detail.

By lengthening the distance through which force is applied to the ball, the long snapper is actually manipulating the impulse-momentum relationship. It is not exactly the distance of force application that alters the velocity of the football, but the time over which force is applied. The relationship states that F•t (impulse) = $m \cdot v_{final} - m \cdot v_{initial}$ (Δ in momentum). Therefore if time (t) is increased, and the force (F) is consistent, then the final velocity (v) of the football will increase as well, since mass (m) is constant and initial velocity can be assumed to be zero.

Blegen et al (2005) also state that the body's momentum can be added to the ball. Momentum (M) is a product of m (mass) • v (velocity). We can assume that the mass of the athlete remains constant, which means that if momentum is altered, it is actually the velocity that is being altered. By sliding backwards towards the punter, the long snapper will have a horizontal velocity (V_h) in that direction. If the long snapper can coincide the release of the football with the backward movement, then the linear velocity of the body is added to the linear velocity of the football created in force production. This means the linear velocity at release may be greater if the athlete is moving in the desired direction, than if the athlete's base of support is stationary.

The airborne phase may also contribute to the long snapper's success by improving accuracy. As the arms rotate about the shoulder joints, a near perfect circle, or parabola, is created since the hands are always the same distance from the axis (centre of the shoulder joint), and this can not be altered. In Figure 2.12A, the circle represents the centre of the shoulder and the arm represented by the rectangular segment between shoulder and ball (red chevron arrows). Notice the semi-circular path of the ball at the bottom of the parabola. In this situation, the ball will be lined up with the target for a very short period of time. If the athlete is moving backward through force production (Figure 2.12B) then the arc created by the arms will be flattened at the bottom. This means the football will be lined up with the desired target for a longer time than in the stationary example. The long snapper must still be skilled enough to release the football during the flattened arc in order to take advantage of the flattened parabola. By incorporating a flattened arc in the delivery of the football, the long snapper's margin of error will be increased considerably, thereby increasing the occurrence of accurate snaps.

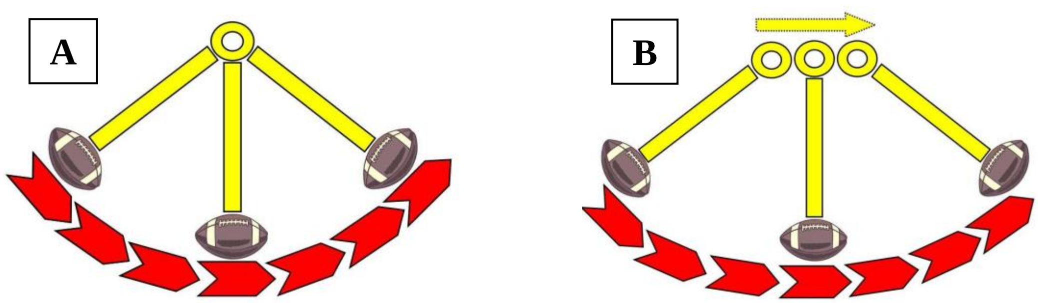


Figure 2.12: A comparison of the parabolic arc of the football when the shoulder remains stationary through force production (A) and the flattened parabolic arc of the football when the athlete is moving backwards through force production (B).

The airborne, or flight phase has been generally under-reported, although does represent a significant adaptation of the skill that may help coaches and instructors identify higher levels of skill in long snappers. The sliding backwards of the body appears to be important to the skill of long snapping since it has positive contributions to both accuracy and velocity of the delivery. By understanding the biomechanical reasoning behind the airborne phase, coaches will be better equipped to recognize it. What is unclear and will hopefully be illuminated in the study is whether it is ideal for the airborne phase to occur prior to, post, or at the same time as the critical instant.

Critical instant

Force production occurs until the moment of release, or critical instant. The critical instant is the moment the long snapper loses control of the football (Henrici, 1967). Henrici states that the pass should be consistent in these respects: 1) It should come backwards toward the punter with no change in velocity during its flight and, 2) It should be at the same height every time when it reaches the punter. These are both remarkably elite characteristics of the long snap. In order to have the ball move towards the punter with nearly no change in velocity, it must be snapped with enough linear horizontal velocity to reach the punter without reaching the apex of its flight. The university long snapper should be able to demonstrate the skill with much less vertical motion of the ball when compared to their high school counterparts if they achieve higher horizontal velocities due to their maturation and physical development.

Zauner (1985) describes the release as the phase following the simultaneous contact of the elbows on the inside of the thighs. At this point, the elbows and knees are both locking out as the ball is being released (Zauner, 1985). It appears that neither the elbows nor knees completely lock out, or fully extend. During pilot study (Appendix E), critical instant seems to occur with measurable flexion remaining in both the elbow and knee joints. Arm/leg contact appears to be a marker as well, since it is from this point of contact that shoulder medial rotation and forearm pronation seem to begin. This means that the knees and elbows are likely nearly fully extended just prior to ball release. Zauner states that for a good snap, the centre releases the ball when “the football is nearly parallel to the ground”, with the nose tilted slightly upward.

Blegen et al (2005) found that at release, the university long snappers demonstrated significantly less hip flexion than the high school snappers (72 ± 1.85° and 49 ± 9.42°). It is notable that within the study by Blegen et al (2005), hip flexion was defined as the acute angle between the torso and the thighs; so a greater number actually equals less hip flexion. This suggested that the university snappers may have simplified the task by decreasing the movements involved, thereby reducing the number of independent components. What was apparent was that the university snappers kept their trunk more horizontal at release, which is important when considering the next phase of the skill. As soon as the ball is released, and the follow through is being initiated, the long snapper must ready himself for contact and his blocking assignments. If the trunk remains more horizontal, there is less range of motion required to get the hips under the torso again in a balanced and stable blocking position.

During the delivery of the long snap, the football is "pushed" across the top of the ball with the left hand, and side of the ball is "pulled" upward with the right hand as it is delivered. Although the left hand acts as more of a guide for keeping the snap at the desired height (Fracas & Marino, 1989), it is also responsible for applying some spin to the ball. The torque created by the left hand is caused by the widespread guide hand rolling over the top of the ball, as the shoulder medially rotates, and the radio-ulnar joints pronate. This can be described as a clockwise direction when viewed from the front. The first release point during skill performance is usually the side of the index or middle finger of the left hand as they push across the top and side of the ball (Figure 2.13A). Once the left hand has been removed from the football, the right hand continues to pull on the ball (Figure 2.13B); but both hands contribute to the rotation of the football.

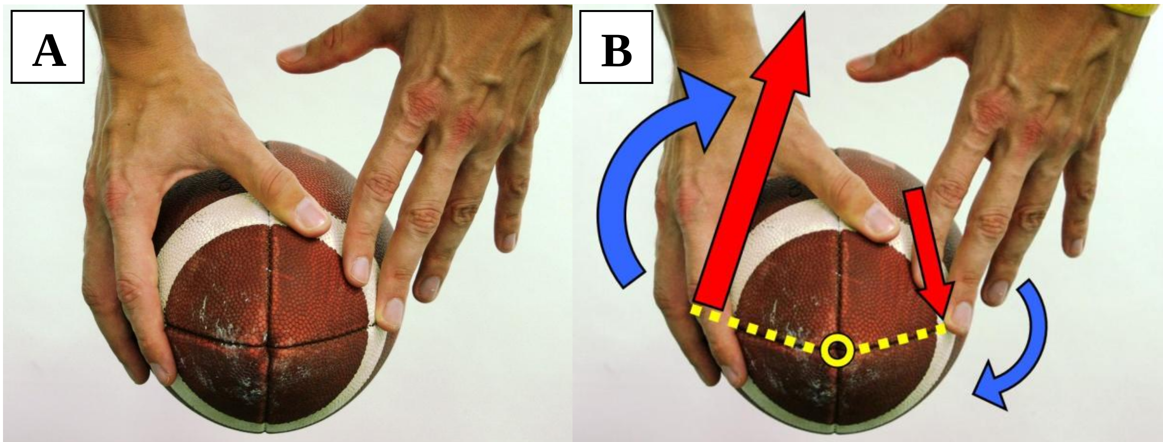


Figure 2.13: Illustrations of the hand position in the long snap prior to release showing the left hand about to release first with the index and middle fingers rolling downward on the ball due to left forearm pronation (A) and a representation of the two torques present about the longitudinal axis of the football (B) giving the ball its spin during flight.

The forces applied by the left and right hand (shown by the red arrows) which are acting to rotate the ball (shown by the curved blue arrows), are acting at some distance (shown by the dotted yellow lines) from the longitudinal axis of the football (shown by the circle). This creates two separate forces acting on the same axis of rotation (the longitudinal centre of the football). Since the forces are not acting through the centre of mass of the football, the effect created is a torque. Torque may be referred to as a rotary force, and is the angular equivalent of linear force (Hall, 2007). The friction between the fingers and the laces and the slightly longer range of motion during pronation cause the right hand to have a greater contribution to the angular velocity of the football, though the left hand should not be underestimated in its contribution to the snap. The left hand, or guide hand will contribute to the spiraling of the football, but will have greater implications in determining the height and angle of release of the football.

The right and left hand are each contributing to two separate forces; the linear force on the football and the angular force on the football. Linearly, the resultant force can be broken down to two contributing vectors. The first of these vectors acts along the 'x' (or horizontal) axis and represents the horizontal velocity component of the ball at release. The second of these vectors acts along the 'y' (or vertical) axis and represents the vertical velocity component of the football at release. Along the x-axis, the horizontal velocity of the football is measured as a linear vector for the left and right hands, in m/s straight back. Along the y-axis, the vertical velocity is also measured as a linear vector for both hands, in m/s straight up or down.

The left hand releases the football before the right hand (Grindle, 1999, Fracas & Marino, 1989) with a resultant velocity vector deviated downward slightly from the horizontal. This breaks down to a relatively small vertical component, as well as a larger horizontal velocity component. Examples are given of the horizontal, vertical and resultant velocity vectors of the left (Figure 2.14A) and right hands (Figure 2.14B).

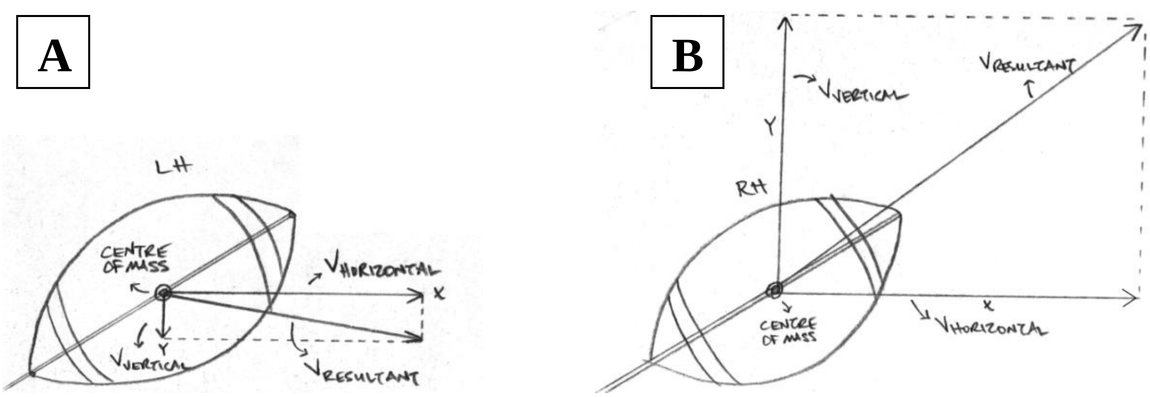


Figure 2.14: Illustration showing relative representations of the left (A) and right hand (B) linear velocity vectors applied to the football at release along the x and y axes.

Controlling the pressure of the top hand during the release determines whether the snap will be too low or too high (Ohton, 1988). The resultant downward vector created by the left hand appears to be important in controlling the ball's height during the snap. The pilot study (Appendix D) revealed that the right hand releases the football approximately

0.02 seconds after the left hand. The right hand produces a greater upward vertical velocity vector which determines release angle. The right and left hands both contribute to the horizontal velocity component of the snap. The correct summation of these velocities determines the ultimate trajectory of the football.

Along the longitudinal axis of the football, the rotational velocity is measured as an angular velocity vector (in degrees or radians per second). Figure 2.13A and 2.13B were views from the front, and demonstrated the axis of rotation of the football as a circle (or dot) in the centre of the ball. The axis of rotation in a well thrown football is ideally limited to this longitudinal centre and passes all the way through the football. If the ball rotates about more than one long axis, it begins to wobble unpredictably; often referred to metaphorically as a wounded duck. The angular axis of rotation can perhaps be better visualized when a dotted line represents the axis of rotation (Figure 2.15) passing along the entire long axis of the ball. The rotation of the football is caused by the right and left hand contributions to angular velocities.

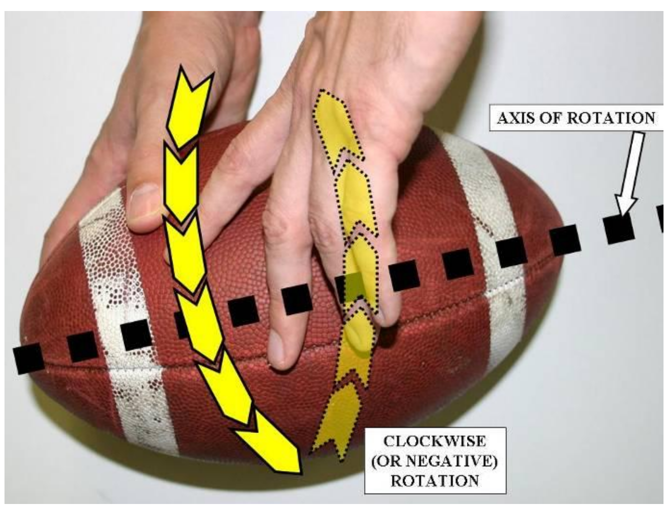


Figure 2.15: Illustration of the angular axis of rotation (dotted line) and the clockwise direction of rotation (clockwise when the long snap is viewed from the front).

The summation of all linear and angular velocity vectors explains the general motion of the football in the air. General motion is defined as a situation where a combination of linear and angular motion is present (Hall, 2007). The two horizontal vectors are added together to determine total horizontal velocity along the x-axis over a given time. The negative (downward) vertical velocity vector is subtracted from the positive (upward) velocity vector to determine total vertical velocity along the y-axis over a given time. The two angular velocity vectors (which determine the final torque applied to the ball) are added together to determine total angular momentum about the football's long axis over a given time.

The position of the torso at release may also have implications for the accuracy of delivery. By reducing hip flexion angles at ball release, the arms and hands of the university snappers seemed to be directed more toward the punter's torso (Blegen et al, 2005), positively influencing the trajectory of the ball during its flight. The greater hip flexion demonstrated by the high school long snappers at release appeared to negatively influence the result (the leading end of the football was higher at release), which led to greater errors in accuracy as well as lesser velocities.

With regards to the velocity of the football at release, various velocities have been reported for athletes of varying ability. Henrici (1967) reported the average high school long snapper's release velocity at 10.65 m/s, with the professional level long snappers' average velocity at 20.57 m/s. Blegen et al (2005) also measured both only at release, and reported the high school snappers' release velocity as 12.52 ± 0.88 m/s, and the university snappers' release velocity as 14.75 ± 1.82 m/s.

Total snap time is most often used to evaluate the long snapper. Coaches can measure total snap time with a stopwatch, and it is the ultimate variable the long snapper wishes to improve. Zauner (1985) rates the snap times from center to punter, where the target is the hip of the punter's kicking leg, as follows: Excellent–between 0.6 to 0.7 seconds, Decent–0.8 seconds, Poor–0.9 to 1.0 seconds. These ratings are for the elite long snapper. Although some university players may achieve these times, it is unlikely to see snap times under 1.0 second at the high school level when delivering the ball 12.8 m. Blegen et al (2005) reported high school long snap times of 1.25 ± 0.19 seconds, and university long snap times of 0.85 ± 0.10 seconds over 11.95 m (14 yards). Henrici (1967) and Slebos (1968) reported snap times closer to 1.5 seconds in their studies of college level athletes. The slower times reported in these studies may be explained by improvements made in technique, instruction, or the overall strength of present day athletes compared to football athletes forty years ago.

Henrici (1967) suggested that the release velocity of the football should be similar to the average velocity of the football through its entire path. This means the long snapper must attempt to minimize the parabolic trajectory of the football, and instead send the ball on the shortest path from release to punter (virtually a straight line). The path that can be traced out by a projectile in two dimensions, or along the horizontal (x-axis) and vertical axis (y-axis) is a parabola (Griffiths, 2006). This trajectory is nearly completely dependent on the release velocity and release angle of the football. The more horizontal velocity that can be given to a projectile, the less vertical motion will be required to reach the desired target. Strength is the maximal force that a muscle or muscle group can generate at a specified velocity (Baechle & Earle, 2000). A stronger athlete will be able to produce more force per unit time than a weaker one, which suggests the stronger long snapper will be able to attain higher release velocities. This means that a stronger long snapper will likely be able to release the football with a decreased angle of trajectory, which will decrease the peak height of the parabola, and therefore reduce flight time and total snap time.

The problem at the high school, and even university level, is that a significant amount of force is required to launch a direct line snap with a low angle of release. The more a long snapper must rely on vertical motion of the football, the longer the ball will be in the air. The question is whether or not this increased vertical path of the ball, and decreased horizontal velocity will allow the punter to stand far enough back from the snapper to have time to execute the kick. If a higher curving football allows the punter to stand further back, then it may likely be worth the trade off. As the athletes improve their release velocity, they can then be instructed to bring the release angle down and attempt a more direct line snap with a less parabolic path. It will be interesting to see whether or not long snappers at the high school or university level are able to demonstrate this elite marker of the skill.

Follow through

Immediately following the critical instant, both hands are thrust backward between the legs toward the punter. The fingers are abducted and the palms are turned outward with forearm pronation after the snap (Fracas & Marino, 1989). The shoulders medially rotate maximally, followed by the complete pronation of the forearms. Grindle (1999) discusses it as a natural breaking of the wrists so that the "fingers are pointed toward the (punter) with palms pointed up and out". The thumbs should be pointed superiorly, while extending the hands as far through the legs as possible (Figure 2.16). While the arms and hands are reaching back toward the punter, they are following through low (Bobo & Dykes, 1998). The long snapper should keep the hands level with or below the knees during the follow through (when viewed from the side) (Blegen et al, 2005).

Figure 2.16: Image showing the follow through of the long snap with the hands staying level with the knees.

The follow through is an opportunity for the athlete to continue movement in the direction of the throwing motion. When discussing the overhand quarterback pass, the American Sport Education Program (2006) indicates that the follow through action in the pass should allow the index finger of the throwing hand, the last finger to act on the football to point to the desired target momentarily. This is comparable to the long snapping instruction of reaching back toward the punter. By reaching back between the legs and having the thumbs pointed upward, the middle fingers, which are the last to release the football in the long snap, both point momentarily at the punter to assist in directing the projectile. This deliberate focus on the target by pointing at it may help to improve long snapping accuracy.

This follow through also allows for sufficient time for the limb segments (particularly the arms and hands) to negatively accelerate courtesy of the antagonistic eccentric muscle contractions occurring post-release. In particular, the rotation of the humerus and forearm must be reversed in a relatively short period of time, by a remarkably short moment arm. The moment arm, or distance perpendicular ($d\perp$) is inversely proportional to force required (F) for the same resultant torque (T); stated in the following formula as $T = F \bullet d\perp$. This can perhaps best be viewed as a further discussion of the angular impulse-momentum relationship. Angular impulse = Δ angular momentum, and angular impulse is a product of torque (T) • time (t). Therefore, angular momentum (H) is a product of the moment of inertia of the limb segment (I) • the angular velocity of the rotating part of the body (ω). If the moment of inertia of the body segment in question remains constant, then the angular velocity can be decreased by either applying a greater torque (T) over less time (t), or a lesser torque over a greater time. The lateral rotators of the shoulders, and the supinator muscles of the forearms are responsible for reversing the rotation at their respective joints. The vast majority of muscle tears occur during eccentric contractions at the myotendinous junctions due to the higher force potentials of eccentric contractions (Nordin & Frankel, 2001). Because of this, it is advisable to increase the amount of the time that the muscles are applying forces, and thereby reduce the resultant torques applied to the joints. By increasing the time, the muscle force may be decreased to achieve the same change in angular impulse, which may result in less injury to these eccentrically contracting muscles.

The follow through in the long snap may be somewhat contraindicated due to the performance demands of the long snapper immediately following the snap. Since the centre must fulfill blocking assignments once the ball is released, some long snappers cut their follow through short in game situations. They do this in order to bring the hips back under the body more quickly, and the arms back in front of the body to prepare for the oncoming contact. Although it is not recommended to stay in the follow through position for longer than necessary, the long snapper must consider completing the motion. This includes the follow through phase of the skill to assist in reducing the risk of muscle injury and possibly improving accuracy.

At the hip, the muscles slowing down any extension will be the hip flexors; namely psoas major and iliacus, as well as tensor fascia latae, sartorius, and rectus femoris. At the knee, the muscles used to negatively accelerate will be the knee flexors; mainly biceps femoris, semitendinosus, and semimembranosus. It is interesting to note that these two-joint muscles of the posterior thigh act both as hip extensors and knee flexors, and are therefore active throughout the entire skill. At the ankle, the dorsiflexor muscles of the anterior compartment may also be active in the follow through; tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius.

The trunk will be negatively accelerated by the muscles that extend the trunk; mainly erector spinae, but assisted by gluteus maximus. Muscles acting at the shoulder to slow the extending limb will include: anterior fibers of the deltoid group, biceps brachii (both heads), brachioradialis, and coracobrachialis. To slow the medial rotation of the shoulder, the lateral rotators will be called upon; mainly infraspinatus and teres minor.

Since they cross both the shoulder and the elbow, biceps brachii (long and short head), brachioradialis, and coracobrachialis will also assist in negatively accelerating the elbow as elbow flexors. Supinating muscles will be mainly responsible for slowing the pronating forearm, and include; biceps brachii (long head) and supinator. Finally, the wrist flexion will be slowed down by the wrist and finger extensor muscles, which mainly include: extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris, and extensor digitorum (Ohton, 1988).

No research was located that described kinematic variables in the long snapping literature when discussing the follow through phase of the skill. Although often mentioned in the description of the skill with qualitative observations such as finishing with the thumbs pointed downward or not releasing the ball above the knees when viewed from the side, no attempts have been made before the current study to quantify the biomechanical variables in the follow through. Informed observation of the follow through may contribute to identifying abnormalities in the delivery of the long snap. Considering the role of the follow through in both accuracy and injury prevention, it must be addressed as a potential indicator of skill level.

Rugby lineout throw-in

Although the long snap is a novel skill, one of the few biomechanically comparable sport skills exists within the game of rugby. During an offensive lineout formation, one player (usually the hooker) must perform a throw-in with the ball. The lineout is the means of restarting the game when the ball has left the field of play (Trewartha et al, 2008). The player is standing upright and facing forward, but the ball is thrown over the head with one or both hands by extending the shoulders and elbows above the head similar to the movements performed during the long snap (although upright and facing forward instead up bent over and throwing backwards). The rugby player will often keep the feet stationary for shorter and medium throws, but is permitted within the rules of the game to take a step forward with the ipsilateral or contralateral leg (Trewartha et al, 2008). Sayers (2004) concluded that the key to throwing greater distances was linked to greater involvement of the lower limb(s), while the contribution of the upper limbs tended to remain constant across varying distances. This re-iterates the difficulty of achieving high velocities in the football long snap, where the feet remain stationary and limit the involvement of the lower limbs.

The grip for the rugby lineout throw is similar to the grip used in the long snap; with the right and left hands often both contributing to the linear and angular velocity of the football. Like the football long snap, there is a clear dominant hand (right for right-handed players) and a secondary or guide hand (left in right-handed players). A key difference between the grips is that the left hand in the rugby lineout throw-in is often placed on the ball with the fingers perpendicular to the seams instead of parallel to them. The hands are also placed on the sides of the rugby ball as opposed to the front and back of the ball as in the long snap (individual variations certainly exist with the lineout throw-in as in the long snap). The hands also tend to be placed more at either extremity of the rugby ball during the throw-in. The lesser potential rotational displacement of the hands due to their position on the ball may result in lesser amounts of torque being applied to the rugby ball. Figure 2.17 shows the grip of the rugby ball just prior to release of the throw-in during a rugby lineout.

Figure 2.17: Side (A) and rear (B) view of the hands during a rugby lineout throw-in.

Another key difference between the rugby throw-in and the football long snap is the release velocity. More specifically, the rugby throw-in has a range of throwing velocities depending on possible player mismatches. The rugby throw-in requires the player to lob the ball to various distances and heights by altering the velocity for each throw to initiate various offensive formations. The long snap requires the football player to throw to a set distance and target each time and attempts to throw with maximal velocity; showing little variation in release velocities. Trewartha et al (2008) studied "flat" and "lob" throw-ins from different distances which included 6, 10, 12, and 14 meters. They reported ball velocities ranging from less than 8.0 to greater than 12.0 m/s. These rugby velocities compare to the faster reported high school football long snappers, but are slower than reported university long snap velocities.

Sayers (2004) noted that players should be allowed to develop individual variations that enable them to feel comfortable when performing the lineout throw-in. This is likely good advice for the long snap as well where individual variations are often seen. Effective force summation is crucial in both skills, but a "one-technique" approach is likely inappropriate and coaches should be prepared to see individual variations in differing athletes.

Dartfish video analysis software

Dartfish video analysis computer software is a patented product founded by InMotion Technologies Limited. SimulCam™ was the original technology developed at the Institute of Technology at Lausanne, Switzerland (company headquarters) in 1997. SimulCam™ allowed two videos clips to be synchronized and viewed side by side simultaneously. In 1998, five international business and IT specialists working for InMotion Technologies Limited first patented a video technology called VideoFinish™ (Dartfish, 2008). VideoFinish™ allowed one moving object to be removed from its original context and superimposed onto a separate video clip. The software evolved to what is now Dartfish Motion Analysis and is currently boasting more than 10,000 users worldwide (Dartfish, 2008). The company recently branched out into other growth areas such as interactive content enhancements as well as developing cutting-edge sport training applications.

During the Beijing 2008 Olympics, Dartfish was used by six independent media companies for broadcast and internet publishing (Dartfish, 2008). NBC (United States) and Televisa (Mexico) employed a full Dartfish service including operators; while CBC (Canada), Canal+ (France), SVT (Sweden), and BBC (United Kingdom) leased Dartfish broadcasting product DartStudio™. All Dartfish systems now operate in high definition for enhanced viewing and analysis.

Recently, Dartfish launched dartfish.tv, a new video casting solution which allows users to take advantage of Dartfish online. This web-based platform has streamlined the process of filming, editing and publishing videos. The software "empowers our customers to produce and share quality videos: better, faster and more successfully than ever before

(Dartfish, 2008). This new online platform means Dartfish users can be instantly connected for immediate dissemination and sharing of knowledge and information.

With reference to this study, Dartfish video analysis was employed by Gabriel Harrington (2003) at the United States Military Academy while studying at Michigan State University. Harrington's project was to produce an instructional DVD on the essentials of long snapping. Dartfish video analysis software was used for all joint measurements, as well as for calculating linear and angular velocities of the bodies or objects involved and was an integral part of the instructional process.

The Biomechanics Master's Program at the University of Manitoba has been using Dartfish since 2003. Former graduates have successfully worked with version 4.5.2 on the following successful thesis projects: "Modifying spike jump landing biomechanics in female adolescent volleyball athletes using video and verbal feedback" (Parsons, 2009), "A comparison of the technique of the 180 degree cutting maneuver performed on grass and on a hardwood floor" (Gerbrandt, 2009), and "A biomechanical analysis of the football quarterback pass and comparison between university and high school athletes" (Toffan, 2009). Other former graduates who successfully used earlier versions of Dartfish software to complete their studies and defend thesis projects were as follows: "A biomechanical comparison of starting technique in speed skating and hockey" (Shackel, 2008), "A biomechanical comparison of the rotational shot put technique used by males and females" (Taylor, 2007), Traditional Arctic Sports: A biomechanical analysis of the one foot and two foot high kick" (Way, 2005), and "A biomechanical comparison of the indoor and outdoor volleyball spike approach and take-off" (Honish, 2005). Further discussion of specific tools available in the Dartfish video analysis software is provided in Chapter 3.

Applications of biomechanics to the long snap

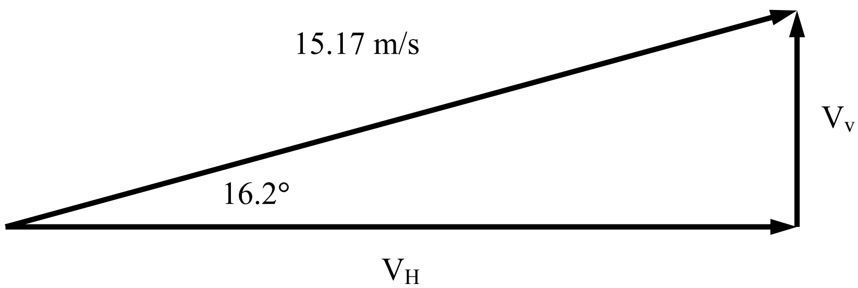
Vectors:

Forces are defined as a push or a pull, and can be visualized as arrows with one arrow head, referred to as vectors. The length of the arrow represents the magnitude of the force, the orientation of the arrow represents its line of application, and the arrowhead indicates its direction of action along that line (McGinnis, 1999). The net force acting on a body or object is the vector sum of all the external forces acting on it; this means the size and direction of the forces must be considered when summing their vector representation. The result of vector addition of forces is also called the resultant force (McGinnis, 1999) because it results from the addition of all the forces present. There is no limit to the number of vectors that can be summed providing this resultant force.

Vector resolution (or the summing of vectors) can be accomplished graphically or algebraically. Graphical resolution means the vectors are drawn to scale in order to solve for the resultant force by manual measure, often resulting in small discrepancies. The trigonometric technique allows for a more mathematical calculation, and can be easily applied to the release of the football in the long snap. The horizontal and vertical velocity vectors are often given to solve for resultant velocity and release angle. In the case of this study, the resultant velocity vector and the release angle are being measured, but can be used to solve for the horizontal and vertical vectors representative of the system. Conceptually, the vertical velocity vector will determine the football's maximum vertical height during its parabolic path; while the horizontal velocity vector will ultimately determine the linear velocity (or horizontal distance covered per unit time) of the football during the long snap.

Sample problem 2.1. with solution:

After completing a Dartfish analysis, the release angle of the long snap to punter was measured to be 16.2° from the horizontal. The release velocity was also measured at 15.17 m/s. Solve for the horizontal (V_H) and vertical (V_V) velocity vectors of the football at release.



Solve for horizontal velocity

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\therefore \cos 16.2 = \frac{\text{horizontal}}{15.17}$$

$$\therefore V_H = (\cos 16.2)(15.17)$$

$$\therefore V_H = 14.568 \text{ m/s}$$

Solve for vertical velocity

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\therefore \sin 16.2 = \frac{\text{vertical}}{15.17}$$

$$\therefore V_V = (\sin 16.2)(15.17)$$

$$\therefore V_V = 4.232 \text{ m/s}$$

Angular motion:

Angular or rotary motion of a body occurs when a torque is applied on a body with a fixed axis (Kreighbaum & Barthels, 1996). Torque is best defined as a rotary effect created by an applied force (Hall, 2007), and is the angular equivalent of linear force. When a force is applied at some distance from the axis of rotation, it is called torque and angular motion occurs (Figure 2.18.). To calculate torque, it is the product of the force applied and the moment arm, where the moment arm is the perpendicular distance from the applied force to the axis of rotation.

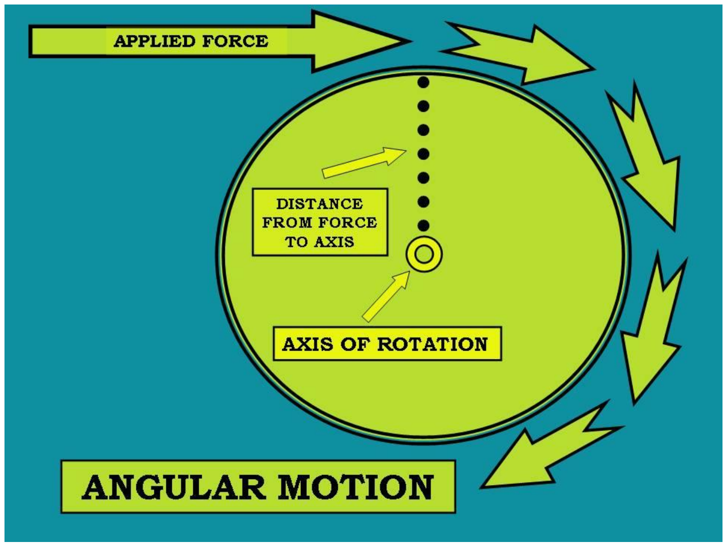


Figure 2.18. Illustration of torque, where a linear force causing angular motion since it is acting at some distance from the axis of rotation.

In describing projectiles (this includes airborne athletes), any unsupported rotating system rotates around an axis that passes through its centre of gravity (Kreighbaum & Barthels, 1996). This means that for a well thrown football, there should only be one axis of rotation, the longitudinal axis of the football. If torque is applied around only one axis, then the ball will have a tighter spiral. This means a more predictable flight path, with less change in linear velocity over time than a wobbling football, due to less surface area facing the oncoming air, resulting in less drag force.

The discussion of torque is particularly relevant to delivering a spiraling football (whether it is the long snapper passing it backwards and between the legs, or the quarterback with an overhead pass). The spin of the ball is dependent on the amount of force that is applied to the outside of the football by the fingertips. Figure 2.19 shows the angular motion (D) as the result of a torque, or a force applied (C) at some perpendicular distance (B) from the axis of rotation (A) of the football.

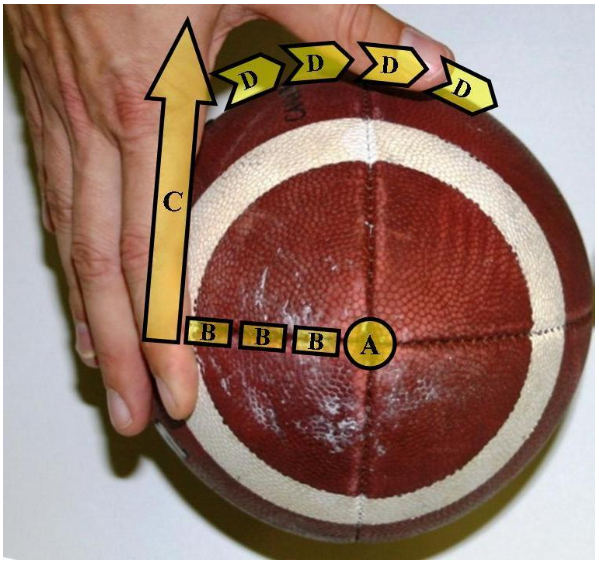


Figure 2.19: Illustration showing the axis of rotation (A), the moment arm or d⊥ (B), the force applied (C), and the angular motion (D) from a front view of the long snap.

Sample problem 2.2. with solution:

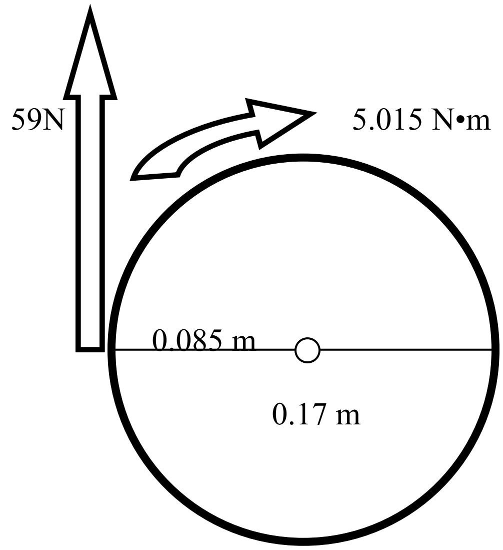
The football has an internal diameter of 0.17 m, and the fingers pull upward with a linear force of 59 N. Calculate the torque applied to the football.

$T = F \cdot d_\perp$

$\therefore T = (59N)(0.17/2)$

$\therefore T = (59)(0.085)$

$\therefore T = 5.015\ N \cdot m$



Newton's 1^{st} law:

Sir Isaac Newton (1642-1727) formulated his first law of motion to reject what the ancient Greeks believed; that "a body moved when there was a force acting on it and that it ceased moving if the force was removed" (Hay, 1993). Newton's first law of motion states that every body continues in its state of rest or motion in a straight line unless compelled to change that state by external forces exerted upon it. Though never proven directly (since it is impossible on Earth to produce a situation in which there are no forces acting on an object), Newton's law is academically accepted as it is consistent with experience (Hay, 1993). Newton's first law of motion is often referred to in the literature as the law of inertia. Inertia can be defined as the tendency of a body to resist a change in its state of motion (Hall, 2007).

When more than one external force exists, it is helpful in biomechanics to sum all the forces on the body or object in question. This way, all the forces can appear to the object as one force, or the net force of the external forces. The body or object has its own inherent force caused by gravity, because it has mass. If the body or object's weight (force of gravity on its mass) is equal to the net external force, then the body or object remains stationary. If the forces are unequal, the net external force causes a change in velocity of the body or object (motion).

If the backswing position is stable and stationary, it demonstrates a situation where the weight of the body and ball are balanced after accounting for all the external forces acting on them since only balancing vertical vectors exist. Figure 2.20 shows the system in balance, where A represents the weight of the body and ball acting through the centre of gravity, while B, C, and D represent the forces being exerted by the earth on the long snapper through the various points of contact. Downward or left vectors are usually given negative values, and upward or right arrows are usually given positive values. Therefore, all the vectors in this system at rest can be summed, and will result in a net force of 0, or no change in velocity will occur. Since the length of a vector represents magnitude, the three upward arrows summed together will be equal to the length of the downward arrow.

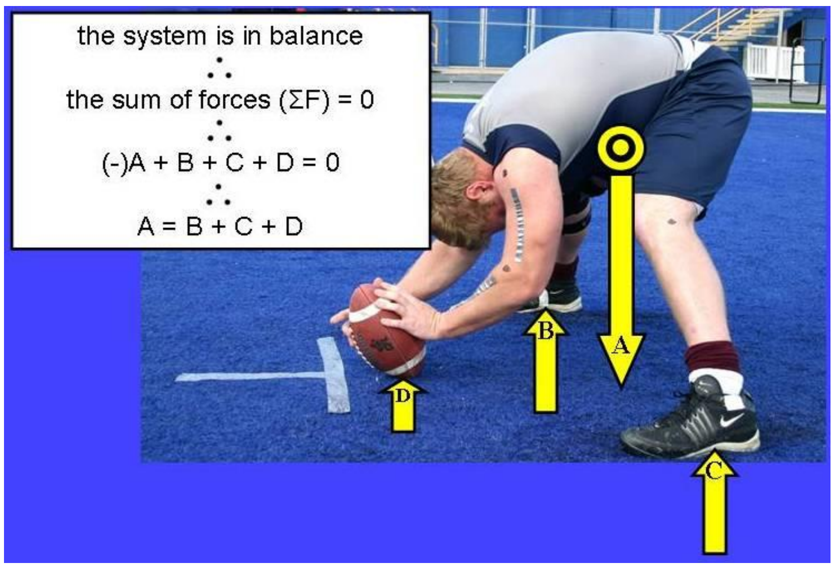


Figure 2.20: Illustration of the force vectors acting on a stationary body.

Newton's first law of motion can be applied to angular motion, where it is perhaps better known as the principle of conservation of angular momentum (Hay, 1993). The angular analogue of Newton's first law states that a rotating body that is airborne will continue to turn about its axis of rotation with constant angular momentum, unless an external couple or eccentric force is exerted upon it. Conceptually with the long snap, the rotating limb segments are not airborne and therefore do not accurately demonstrate the principle of conservation of angular momentum. The rotation of the limb segments about the joints may be altered though by eccentrically contracting muscles, as seen in the follow through. The ball in flight is a more accurate demonstration of the conservation of angular momentum since it is airborne and will continue to rotate unless acted upon by an external force. The rotation of the football will be produced by the long snapper and altered by the punter when he attempts to catch it. To stop the football from spinning, the player must alter the angular momentum of the ball by applying external forces to it. Sample calculations for manipulating the angular momentum of the football will be demonstrated later in the discussion of the impulse-momentum relationship.

Newton's 2nd law:

Isaac Newton also summarized the effects of applying forces to bodies or objects when the total forces acting on the system are not in balance. The result is his formulation of the second law of motion which states "the rate of change of momentum of a body is proportional to the force causing it and the change takes place in the direction in which the force acts" (Hay, 1993). Often added to the original statement of the law, is that the rate of change of momentum is also inversely proportional to the body's mass. This means that as the mass of the body or object goes up, the rate of change of momentum goes down (provided the same force is applied). The second law of linear motion is often referred to as the law of acceleration.

Algebraically, this can be expressed as $F = m \bullet v_{final} - m \bullet v_{initial} / t$; where F is the force applied, m is the mass of the body or object, v is the velocity, and t is the time. For a body with a constant mass, the formula can be reduced to $F = m \bullet a$; where a in the equation represents the acceleration of the body or object (equal to $v_{final} - v_{initial} / t$). The unit of force is kg•m/s^2, which is defined as the Newton (N). The force required to produce an acceleration of 1 m/s^2 in a body of 1 kg mass (Hay, 1993) is equivalent to 1 N. These formulae allow for the calculation of muscle force acting on a body or object provided the other variables are known, or measurable.

Sample problem 2.3. with solution:

Calculate the muscle force required in the long snap to deliver the football in 0.083 seconds with a release velocity of 14.69 m/s. By knowing the time of force application, and the final and initial velocity of the football (since it started at rest), acceleration can be determined:

$$a = (v_{final} - v_{initial}) / t$$

$$\therefore\ a = (14.69 \text{ m/s} - 0) / 0.083 \text{ seconds}$$

$$\therefore\ a = 176.988 \text{ m/s}^2$$

Once solved for, the acceleration and the known mass of the football are used to determine the force (or the sum of the forces) required in the system to achieve the recorded release velocity:

$$F = m \bullet a$$

$$\therefore\ F = (0.411 \text{ kg})\ (176.988 \text{ m/s}^2)$$

$$\therefore\ F = 72.742 \text{ N (kg} \bullet \text{m/s}^2)$$

Newton's second law of motion can also be applied to angular motion, and is algebraically stated as $T = I \bullet \omega_{final} - I \bullet \omega_{initial} / t$; where T is the torque applied, I is the moment of inertia, ω is the angular velocity, and t is the time. The law states "the rate of change of angular momentum of a body is proportional to the torque causing it and the change takes place in the direction in which the torque acts" (Hay, 1993). The formula can be further reduced to $T = I\alpha$, where α represents the angular acceleration required by the system. These formulae allow for the calculation of the torque applied to the football provided the other variables are known, or measurable.

Sample problem 2.4. with solution:

Calculate the torque required in the long snap to spin the football in 0.083 seconds with an angular velocity at release of 2650.75 °/s (46.261 rads/s). By knowing the time of torque application, and the final and initial angular velocity of the football (since it started at rest), angular acceleration (α) can be determined:

$$\alpha = (\omega_{final} - \omega_{initial}) / t$$

$$\therefore \ \alpha = (46.261 \text{ rads/s} - 0) / 0.083 \text{ seconds}$$

$$\therefore \ \alpha = 557.361 \text{ rads/s}^2$$

Once solved for, the angular acceleration and the known moment of inertia of the football are used to determine the torque (or sum of torques) required in the system to achieve the recorded angular velocity at release:

$$T = I \bullet \alpha$$

$$\therefore \ T = (0.002138 \text{ kg} \bullet \text{m}^2)(557.361 \text{ rads/s}^2)$$

$$\therefore \ T = 1.192 \text{ N} \bullet \text{m}$$

The moment of inertia of a body is the property representing the body's resistance to angular acceleration (Hall, 2007), based on both the mass and the distance the summed mass of all the particles is distributed from the axis of rotation. The formula for moment of inertia is $I = mk^2$; where I is the moment of inertia (in kg•m^2), m is the mass of the body or object, and k is the radius of gyration. Since the mass and distribution of mass of the football remains constant, its moment of inertia also remains constant.

The moment of inertia of a football is difficult to calculate accurately, since it is an odd shape (a prolate spheroid) where the outer shell makes up the mass about a hollow centre. A simple sample calculation to demonstrate solving for moment of inertia could be the product of the mass of the football (0.411 kg) by the radius of the football (0.085 m) squared. This would result in a moment of inertia of 0.002969 kg•m^2, but assumes a cylindrical object with a solid mass. Horn & Fearn (2008) conducted a more accurate calculation of the moment of inertia of the football; and it was reported at 0.002138 kg•m^2, which will be the value used in this study. Unfortunately, Horn & Fearn based these calculations of moment of inertia on the dimensions of an American football. Due to the slight difference in the size of the footballs between leagues, a Canadian football may in fact have a slightly larger moment of inertia due to its less prolate spheroid shape, making it slightly shorter and slightly wider than its American counterpart.

Although the majority of the mass of the football is only in its outer shell (not to mention the additional mass of the laces), the prolate spheroid shape of the football means that the converging ends of the shell move more of the football's mass closer to the axis of rotation. As the outer shell converges to a point on either end of the ball, the overall radius of gyration of the sum of all mass particles is reduced. Therefore, assuming a radius of gyration that is half the football's inner diameter will overestimate moment of inertia, as we have seen in the sample calculation. It is for this reason that the moment of inertia about the longitudinal axis of a football must smaller than if the shape was assumed to be cylindrical and of a solid mass.

Impulse-momentum relationship:

The impulse-momentum relationship states that when an impulse acts on a system, the result is a change in the system's total momentum (Hall, 2007); and its formula is stated as $F \cdot t = \Delta M$, or $F \cdot t = m \cdot v_{final} - m \cdot v_{initial}$. Before discussing the relationship, the terms must be defined. The product of the force (F) and the time during which the force acts (t) is defined as the impulse of the force (Hay, 1993), and is stated as linear impulse = $F \cdot t$. Linear momentum is the product of an object's mass (m) and its linear velocity (v), and is stated as $M = m \cdot v$; where M is the momentum.

Conceptually, the impulse-momentum relationship is a manipulation of Newton's second law ($F = m \cdot v_{final} - m \cdot v_{initial} / t$), where the time (t) has been multiplied by the force to represent the impulse on the left side of the equation, and the change in momentum is represented on the right by the difference in the product of mass by final and initial velocities. Similar impulses can be created by a small force over a large period of time, or conversely a large force over a small period of time. The amount of impulse generated by the human body is often intentionally manipulated (Hall, 2007). These situations often involve increasing the time to decrease the force; such as when landing from a jump or catching a hard-thrown ball. In the case of the long snap, a relatively larger force is applied over a relatively short time to keep total snap time as short as possible. Using the variables from sample problem 2.3., the impulse-momentum relationship can be used to estimate the forces required to snap a football if the mass, time, and velocity are known:

$$\text{Linear impulse} = \Delta M \quad \therefore \quad F \cdot t = m \cdot v_{final} - m \cdot v_{initial}$$

$$\therefore \quad F \cdot 0.083 \text{ seconds} = (0.411 \text{ kg})(14.69 \text{ m/s}) - (0.411 \text{ kg})(0)$$

$$\therefore \quad F = 72.742 \text{ N}$$

The angular impulse-momentum relationship is also a manipulation of the law of (angular) acceleration. The relationship is stated as $T \cdot t = \Delta H$; or $T \cdot t = I \cdot \omega_{final} - I \cdot \omega_{initial}$. The product of the torque (T) and the time during which the torque acts (t) is defined as the angular impulse, and is stated as angular impulse = $T \cdot t$. Angular momentum is the product of an object's moment of inertia (I) and its angular velocity (ω), and can be stated as $H = I \cdot \omega$; where H is the angular momentum of the system.

In throwing situations like the long snap, the object is to maximize the angular impulse exerted on the football about the shoulder and elbow joints, to maximize the ultimate horizontal displacement following release (Hall, 2007). The long snapper also applies a torque to the side of the football during release to spin the football (produce angular momentum). By increasing the torque (T) applied, the angular velocity (ω) is increased; which represents a proportional increase in angular momentum (H). Similar to the role of the football's mass in the linear discussion, the moment of inertia of the football remains constant throughout the skill. This means that the only means to increase the angular momentum of the football during the snap is to increase the applied impulse.

Using the variables from sample problem 2.4., the impulse-momentum relationship can be used to estimate the torque required to snap a football:

$$\text{Angular impulse} = \Delta H \quad \therefore \quad T \bullet t = I \bullet \omega_{final} - I \bullet \omega_{initial}$$

$$\therefore \quad T \bullet 0.083 \text{ seconds} = (0.002138 \text{ kg} \bullet \text{m}^2)(46.261\ °/\text{sec}) - (0.002138 \text{ kg} \bullet \text{m}^2)(0)$$

$$\therefore \quad T = 1.192 \text{ N} \bullet \text{m}$$

Chapter 3

Methods

Subjects

Twenty (N=20) amateur male Canadian football players who specialize in the long snap to punter on their respective squads participated in this study. Ten distance snappers were recruited from local high school teams to provide athletes at the high school level (aged 15-18). Ten distance snappers were also recruited from local university and junior league teams to provide athletes at the university level (aged 18+). Filming took place prior to or during scheduled team practices, with permission granted from the head coach, and head administrator for the high school students. For any filming that took place outside of team practices (for example at another team's conditioning session), individual arrangements were made with the athletes and coaches involved. Consent forms were supplied to all potential subjects, coaches, and administrators prior to the filming session.

All of the participants were instructed to bring the completed consent form (Appendix B) to the session, or to complete an informed consent form prior to filming. Athletes under the age of 18 were required to provide the informed consent of a parent or guardian. Subjects who were under 18 years old were also asked to read and complete a letter of assent (Appendix C) prior to being filmed. Subjects wore their own footwear for the trials. Subjects were asked to refrain from wearing any other protective equipment (helmets or shoulder pads) during testing, and were asked to snap a regulation sized football. Long snappers may or may not wear gloves, and although this would likely increase friction between the fingers and the ball, subjects who normally wore gloves were allowed to do so if that was part of their regular equipment.

Filming technique

Trials were recorded at each team's practice facility during a scheduled session, or at a pre-determined location convenient for both parties. Sessions all followed the same protocol. A four camera setup (Fig. 3.1) was used in order to film the views required to measure the necessary variables. All four cameras were Canon digital video camcorders with built-in image stabilizers; while manual set up options were used to film the snaps to allow for the best possible video quality. Shutter speeds varied depending on available light, but the minimum setting used was 1/500 for indoor filming (with extra lighting), and the maximum setting used was 1/2000 for outdoor filming sessions. Video was recorded to miniDV cassette tapes on standard play (SP) setting before importing the data with Dartfish Team Pro 4.5.2 software to a Toshiba Satellite A200 TH7 laptop computer for analysis.

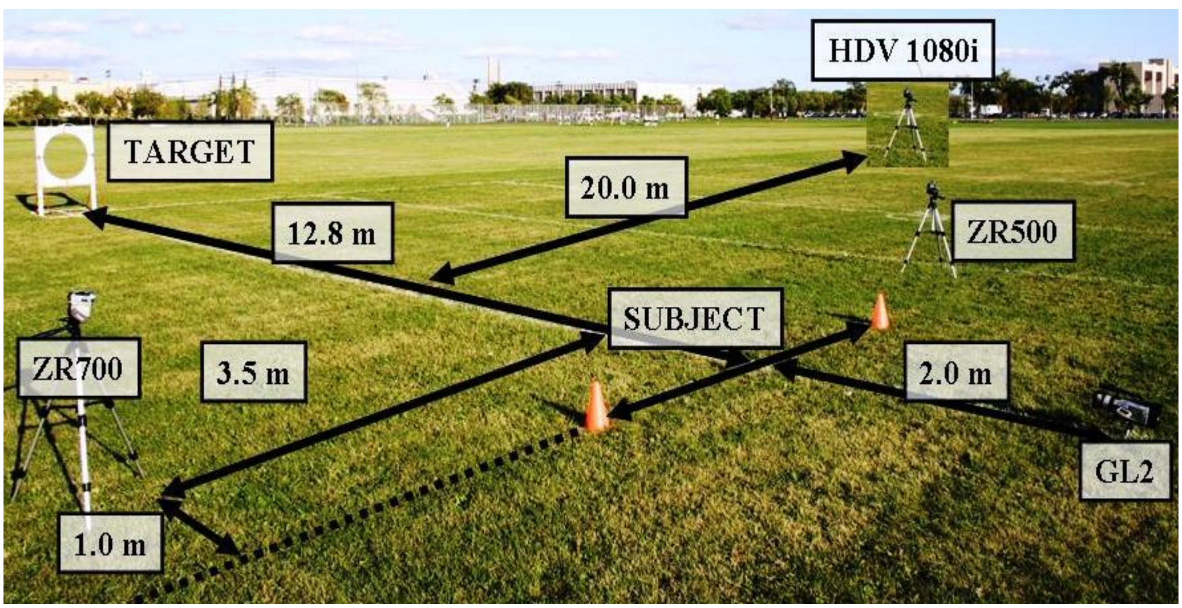


Figure 3.1: Camera placement for data collection.

One Canon GL2 camera was positioned 2 m in front of the subject on a 0.10 meter high tripod. The camera was positioned at an angle (10° to the horizontal) to capture not only the snapping motion, but a clear view of the target to confirm hits and proximity of misses. This anterior view allowed the investigator to measure subject stance width, shoulder medial rotation, forearm pronation, angular deviation of the feet from the sagittal plane in the stance, and provided a valuable view of the distal phalanges of the hand releasing the football.

The second and third cameras (Canon ZR500 and ZR700) were positioned on either side (to the right and left) of the athlete. These two cameras were on 1 meter high tripods, at a distance of 3.5 meters from an imaginary line bisecting the subject in the sagittal plane, placed 1 m back from the extended line of scrimmage. The captured video from these two cameras permitted joint measurements in the sagittal plane (forward trunk lean from the horizontal, hip flexion and extension, knee flexion and extension, ankle dorsiflexion and plantarflexion, shoulder flexion and extension, and velocities of the joints), various distance measurements (heels to line of scrimmage, ball height at release, horizontal distance covered in airborne phase), and ball release velocity.

The fourth and final camera (Canon HDV 1080i) was positioned on a 1 meter high tripod to one side of the performed skill (the side may differ to allow the camera to face away from the sun), at a distance of 20 meters from the imaginary line bisecting the subject in the sagittal plane. The camera was positioned at the mid-point between the target and the subject to capture the entire flight of the football, as well as the subject and the target. The video taken allowed for the calculation of total snap time, average linear velocity of the football, average angular velocity of the football (by counting the number of revolutions of the football), and angular momentum of the football.

Target

The trials that demonstrated the highest release velocities were the main focus of the study. Since velocity and accuracy are both paramount in the long snap, a target was constructed to identify the trials with the highest velocities as accurately delivered snaps. The most accurate (closest to the "hit" zone) of the fastest trials was analyzed. The "hit" zone of the target was a cutout, as opposed to a series of concentric circles which have been used in other studies (Henrici, 1967, Harrington, 2003, Blegen et al, 2005). The target was constructed to simulate the height of the punter's hip, and the cutout size attempted to represent the acceptable margin of error for a "good" snap.

In the high school game, perfect snaps are less frequent, but any acceptable snap that is possible to catch may be effective in a game. Provided the punter does not need to crouch, jump, or move more than one step laterally, the expectation for the punter is to catch the ball. The size of the hole in the target was determined based on measures collected from two university level punters. Both punters were asked to hold their hands in the ideal receiving position for the football, which was just below 1.0 m for both athletes. The radius of the hole was determined by how far the punters could move their hands comfortably to the left or right (without moving their feet) and still be able to catch the football with both hands. A central spot between the hands was found to be approximately 0.34 m from the starting position. Based on these measures, the target design specified the centre of the target at 0.90 m, and the radius of the circle was 0.35 m.

The target was designed to fold down for portability, and to allow a single person carry with relative ease. The raw materials for construction of the target were: 1 sheet of 3/4" plywood (1 meter x 1 meter), 8 meters of 2" x 3" lumber, 4 screw-in eyelets (1.5" diameter), 2 elastic cords with hooks, 1 meter of chain link, 2 standard door hinges, netting (1 meter x 1 meter), duct tape, nylon cable zip ties, and 1.5" stainless steel countersunk screws (x12). Target design can be seen in Figure 3.2.

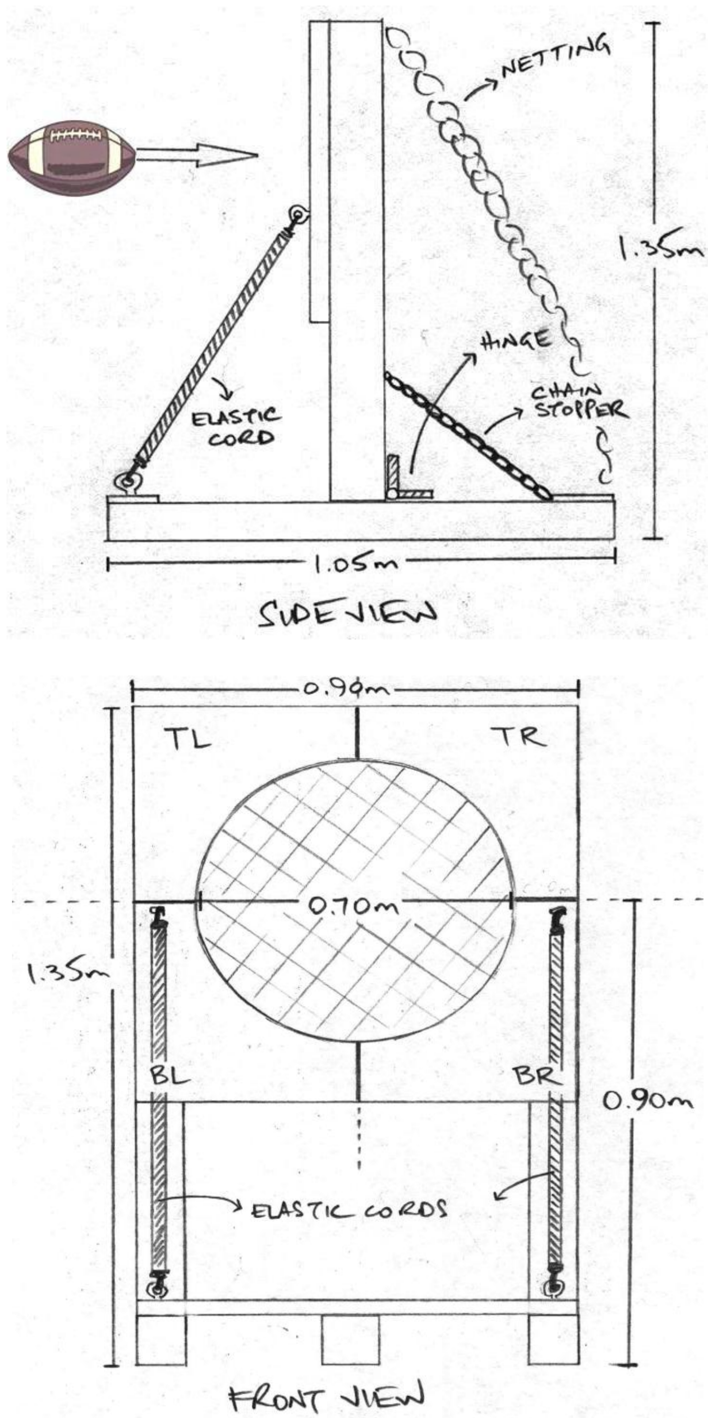


Figure 3.2: Side view and front view of target design specifications.

Target design remained consistent during construction (although a 4” door handle was attached to one side to increase ease of carrying the target which was not included in the original design). The sheet of 3/4” plywood was cut down to 0.90 m x 0.90 m and attached with the countersunk screws to two 1.28 meter lengths of the 2” x 3” lumber. The hole was a circle, cut out with a jigsaw and the target circle had a diameter of 0.70 meters. The centre point of the hole was 0.90 meters from the ground, and the top of the target was 1.35 meters high. Three identical 1.05 meter lengths of the 2” x 3” lumber form the base of the target. Two support beams were placed perpendicular to these three lengths (at the ends of the boards) and were then attached with 1.5” stainless steel countersunk screws from the top. The door hinges attached the upper portion of the target to the base, and fold backwards to improve portability of the target. The screw-in eyelets were placed on the front side of the target and the front portion of the base. The elastic cords were attached to these in order to hold the target upright, and give the target the ability to absorb the force of the ball on impact and recoil to its original position.

The chain link section was designed to stop the hinges from bending past 90°, and to act as a safety stop mechanism. The chain was cut in two lengths, and attached to the tops of the target beams, at the rear portion of the base. The netting was positioned on the rear of the target, and was attached with cable zip ties by drilling holes along the sides of the target and securing them after with duct tape. Finally, two holes were drilled in the front portion of the base. Two bent wire hooks were placed through these holes and pushed into the ground to stop the front of the target from lifting on impact when filming on grass. When filming on turf instead of grass, a car tire was placed on the front of the target for the same reason. Figure 3.3 shows the side and front view of the constructed target.

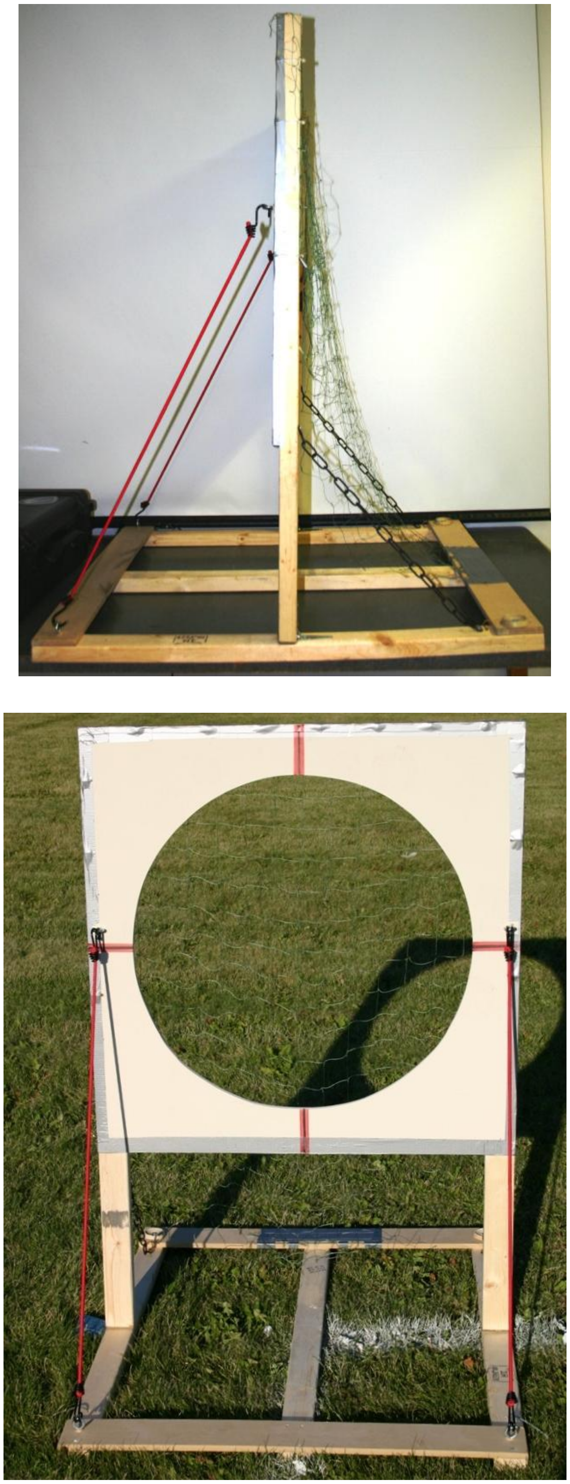


Figure 3.3: Side view and front view of constructed target.

Filming protocol

The filming either took place at the respective team's practice facilities or the subjects were invited to University Stadium or the Indoor Soccer Complex at the University of Manitoba if this proved more convenient for the subjects or coaches. Ideally all filming would have taken place outdoors, since the majority of games at the high school and university levels are played outdoors. Outdoor filming would also greatly improve the quality of the video since significantly higher shutter speeds are possible with more available sunlight. Weather conditions did become a deterrent factor to filming outdoors, and extreme wind or cold was cause for rescheduling filming sessions, or filming to be moved indoors. The number of athletes filmed at each session depended on the available athletes, as well as the total number of distance snap specialists on the team's roster. Equipment setup took 30-45 minutes, while actual filming time per subject was less than 20 minutes. After warm-up, each athlete executed 5-10 warm-up snaps to familiarize themselves with the target and surrounding cameras, followed by a minimum of 10 trials for data collection.

Subjects' date of birth, height, mass, hamstring flexibility and informed consent were all recorded prior to filming. Lightweight markers (athletic tape) were placed on the centre of the shoulder, elbow, hip, knee, ankle, and instep to improve the consistency of the video analysis. A strip of thin, lightweight reflective tape was also placed on the anterior midline and lateral border of the humerus (along the line of the deltoid tuberosity), as well as the lateral border of the radius (along an imaginary line from lateral humeral epicondyle to radial styloid process). This tape line assisted the researcher in the estimation of humeral rotation and forearm pronation.

Following sufficient individualized warm-up, the subjects were instructed on study protocol and hamstring flexibility was recorded. Flexibility was rated (0, 1, 2, 3) based on a standing toe touch position. The intention was to measure the distance of the proximity of the palmar surface of the hands to the ground (with fully extended wrists). There proved to be a large variation in the range of motion at the wrist when fully extended voluntarily, making it difficult to be consistent with distance measures between subjects. Therefore, a rating scale (0,1,2,3) was devised by the researcher to evaluate hamstring and posterior spine flexibility. Subjects were asked to keep knees extended and reach down to the ground as far as possible (with controlled movement during the downward phase). If the subject could touch the ground, subjects were instructed to continue to roll the fingers onto the ground to a maximum position of flexibility with the palms flat (Figure 3.4). The rating went as follows: 0–the fingers do not touch the ground, 1–fingers or finger pads (up to the distal interphalangeal joints) touch the ground, 2–the palmar surface of the fingers from distal interphalangeal joints to metacarpophalangeal joints is able to touch the ground, and 3–the palms are able to rest on the ground.

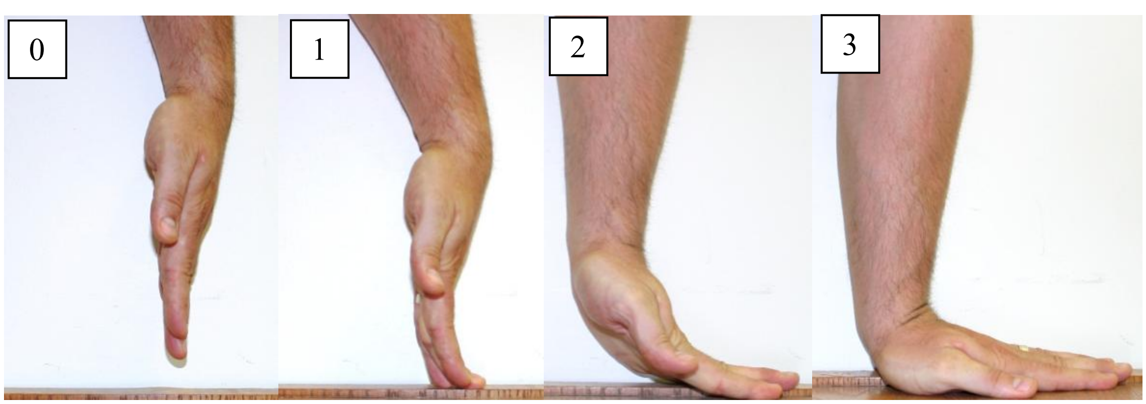


Figure 3.4: Examples of hand positions that would receive ratings of 0, 1, 2, or 3 when the subject is performing a standing toe touch movement with knees fully extended to evaluate hamstring and posterior trunk flexibility.

The football was placed on the line of scrimmage for each of the subjects' trials by the investigator or another player. Subjects were asked to approach the ball as they would in a game and assume their individual stance or set-up. Subjects were instructed to perform the snap as they would in a game, with instructions to snap as quickly and accurately as possible. Each subject was instructed to perform ten consecutive trials. Between each trial, subjects were asked to leave the line of scrimmage and walk around a designated pylon before returning to the line of scrimmage for the next trial. This provided a more accurate measure of the preliminary movements for each trial, since the feet must be placed again in position before each snap. It also simulated more of a game situation, since a distance snapper is unlikely to perform consecutive snaps in competition without resetting their stance.

All subjects, regardless of playing level, performed their snaps to the same target distance of 12.8 meters (14 yards). Although each athlete may have been accustomed to slight variations of this distance depending on their skill or their punter, identical distance was imperative for this study to be able to normalize the data.

In game situations, it is difficult to remove the skill from its context; as one discrete task amidst a game of high speed collisions and decisions. During a game, the centre is required to perform a good snap, as well as fulfill his blocking assignment(s), and then sprint downfield for defensive coverage. This author was hoping to create a situation with little or no contextual interference for specific skill analysis. Contextual interference is the interference that results from practicing various tasks or skills within the context of a practice (Magill, 2001). In order to achieve this, the subjects in this study were not asked to block or provide downfield coverage after the snap. To isolate and analyze the skill properly, it was necessary to observe it in a situation with low contextual interference.

Instruction of test protocol occurred prior to the beginning of the trials, and no instruction or feedback regarding snapping technique was given to the subjects during the filming. This was to ensure that the investigator did not influence or bias the performance of the subjects during the trials. If coaches were present, they were asked to refrain from giving feedback to the subjects during the trials but discussion was encouraged once filming was complete. The only conversation between investigator and subject, once the testing begins, was to relay the number of completed trials prior to each snap, and the result of each trial as a “hit” or “miss”, for example “2 – hit”.

Digital video analysis

Once filming was complete, the video was imported to a Toshiba A200 TH7 laptop with Dartfish Team Pro 4.5.2 software. Within the Dartfish software, the In the Action setting was used, which imports the video through a digital camcorder using a 4-pin to 4-pin firewire for transfer. Once the video was imported, it was opened in the Dartfish Analyzer mode which allowed the investigator to view all four camera angles for each trial at the same time with a split-screen function. Clips were also synchronized temporally using the timeline feature, which allows all four clips to be viewed in the same time frame (to the nearest $1/60^{th}$ of a second). The Analyzer mode also allowed the investigator to play the video frame by frame for analysis at $1/60^{th}$ of a second.

Although all footage was imported and viewed for trial selection, only one snap from each athlete was analyzed. Since release velocity was the dependent variable, the fastest three trials from each subject were identified. Of these three trials with the highest release velocities, the most accurate (closest to the centre of the target) was chosen for analysis for each subject. If all three of the fastest velocity trials missed the target by a significant margin (visual observation by the researcher), then the researcher continued to locate the fastest trials until one was determined to be within an acceptable range.

The Dartfish Team Pro 4.5.2 software is equipped with a variety of tools that can be used to draw lines, measure time, measure distances, measure joint angles, or track moving objects in two-dimensional space. These functions allowed the investigator to measure specific variables, and calculate angular and linear velocities based on the linear or angular displacement of body segments over time. The Analyzer angle tool was used to measure all joint angles, using the 180-degree system. In anatomical position, according to the 180-degree system, all joints are in a position of zero degrees. Any deviation from anatomical position was then measured. Anatomical position can be best described as a standing position, with feet approximately shoulder width apart, and hands and arms alongside the body with the palms facing forward.

In addition to the measurement tools, Dartfish is capable of playing the video clips frame by frame to allow the researcher to analyze the skills qualitatively. This frame by frame analysis can be easily done backwards or forwards and is a useful tool for playback. Dartfish video analysis software 4.5.2 also allows the user to zoom in, or magnify the video clip at any time. This tool serves an important purpose for improving reliability when marking joint centres, or setting the length of reference markers for distance conversion.

Video analysis was used to measure quantitative variables from the data. These variables helped to define the techniques employed by differing skill levels (high school and university) of distance snappers. The dependent variable (primary variable of interest) was the release velocity of the football (m/s) when delivered with accuracy. The data gathered from the sagittal camera angles allowed the investigator to determine the release velocity of the football. The data gathered from the frontal camera angle allowed the investigator to determine how close the football came to the centre of the target. Several other variables were collected during the investigation, and these were collected in order to construct a complete biomechanical framework for each subject; providing the necessary information to compare the snapping techniques used by high school and university football players. A complete list of the variables measured in the study is outlined by phase and shown in Table 3.1. These specific variables were determined by examining the available literature on this skill, as well as related studies of skill performance.

Table 3.1: List of variables measured in subjects analyzed.

Phase of the Skill	Variable(s) Measured
Preliminary Movements	• Hamstring flexibility (0,1,2,3) • Stance width (m) • Stance width (% of standing height) • R heel distance from line of scrimmage (m) • L heel distance from line of scrimmage (m) • Deviation of right foot out-turn from sagittal plane (°) • Deviation of left foot out-turn from sagittal plane (°)
Backswing	• Forward trunk lean (° deviated from horizontal) • R shoulder flexion (°) • L shoulder flexion (°) • R elbow flexion (°) • L elbow flexion (°) • Hip flexion (°) • Knee flexion (°) • Ankle dorsiflexion (°)
Force production	• Maximum R elbow flexion (°) • Maximum L elbow flexion (°) • Maximum spinal flexion curve (m) • R shoulder extension ROM (°) • R shoulder extension time (s) • R shoulder extension velocity (°/sec) • L shoulder extension ROM (°) • L shoulder extension time (s) • L shoulder extension velocity (°/sec) • R elbow extension ROM (°) • R elbow extension time (s) • R elbow extension velocity (°/sec) • L elbow extension ROM (°) • L elbow extension time (s) • L elbow extension velocity (°/sec) • Hip extension ROM (°) • Hip extension time (s) • Hip extension velocity (°/sec) • Knee extension ROM (°) • Knee extension time (s) • Knee extension velocity (°/sec) • Ankle plantarflexion ROM (°) • Ankle plantarflexion time (s) • Ankle plantarflexion velocity (°/sec)

Force production variables (continued)	• R shoulder medial rotation ROM (°) • R shoulder medial rotation time (s) • R shoulder medial rotation velocity (°/sec) • L shoulder medial rotation ROM (°) • L shoulder medial rotation time (s) • L shoulder medial rotation velocity (°/sec) • R forearm pronation ROM (°) • R forearm pronation time (s) • R forearm pronation velocity (°/sec) • L forearm pronation ROM (°) • L forearm pronation time (s) • L forearm pronation velocity (°/sec) • Release time / time of force production (s)
Critical Instant	• Total airborne time of the athlete (s) • R heel distance covered (m) • L heel distance covered (m) • Mean distance covered (average of both feet) (m) • Total flight time (ball in the air in sec.) • Total snap time (start of movement to 12.8 m in sec.) • Release height of football (m) • Release height (as % standing height) • Release velocity of football (m/s) • Release angle of football (° from horizontal) • Average linear velocity of ball (m/s) • Average angular velocity of ball (°/sec) • Angular momentum of ball (kg•m^2/s) • Forward trunk lean (° deviated from horizontal) • R shoulder flexion (°) • L shoulder flexion (°) • R elbow flexion (°) • L elbow flexion (°) • Hip flexion (°) • Knee flexion (°) • Ankle plantarflexion (°)
Follow through	• Trunk forward lean (° from horizontal) • R shoulder flexion (°) • L shoulder flexion (°) • Hip flexion (°) • Knee flexion (°)

Sample of variables measured

The 180° system, which refers all joint measurements back to anatomical position, was employed with the tools available in Dartfish 4.5.2. In anatomical position, all joints are in a position of 0°. Any deviation from this position can then be measured, with posterior movements being termed extension or hyperextension. The prime phases of interest for joint measurements in this study were backswing and critical instant. These measures allowed for the calculation of angular velocities during force production (which occurs between backswing and critical instant) by solving for the angular displacement of the joint over a given time frame. The force production phase also contains the occurrence of arm/leg contact from which point shoulder medial rotation and forearm pronation occur.

Forward trunk lean, shoulder flexion, elbow flexion, hip flexion, knee flexion, and ankle dorsiflexion were measured from the left and right sagittal views using the angle tool in Analyzer mode of the Dartfish program. A sample of three of these measures (shoulder, hip, and knee flexion) in the backswing can be seen in Figure 3.5. The respective joint centres that were marked with adhesive tape are being used to define the lines necessary to measure the angles.

Shoulder flexion is shown (Figure 3.5A) as the angle measured between the line of the trunk (from hip to shoulder) and the line of the upper arm (from the centre of the shoulder joint to the centre of the elbow joint). Hip flexion is shown (Figure 3.5B) as the angle measured between the extended line of the trunk and the line of the thigh (from the centre of the hip joint to the centre of the knee joint). Knee flexion (Figure 3.5C) is shown as the angle measured between the extended line of the thigh and the line of the lower leg (from the centre of the knee joint to the lateral malleolus of the fibula).

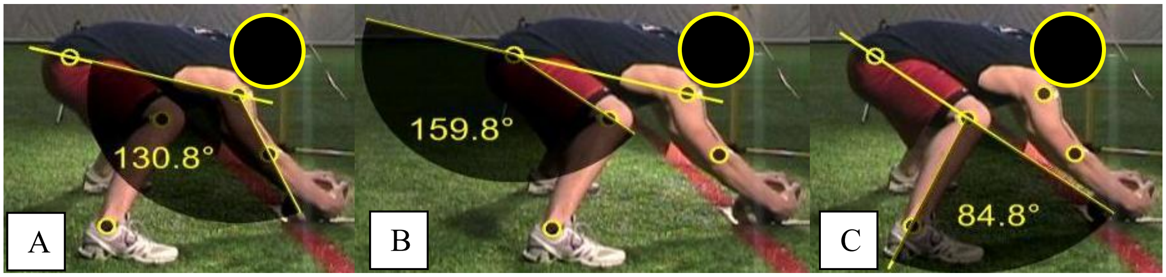


Figure 3.5: Sample measures of shoulder (A), hip (B), and knee flexion (C) angles.

Within the force production phase, it was important to identify the point in time when the posterior surface of the arm contacts the anterior surface of the thigh (arm/leg contact). It is from this point of contact (Figure 3.6A) that the shoulders begin to medially rotate, coupled with forearm pronation. This was the baseline from which shoulder medial rotation range of motion was measured. The line in Figure 3.6A is connecting the joint centre marker on the lateral shoulder and the lateral epicondyle of the humerus. With the shoulder joint remaining nearly stable until release, the second line is drawn over the same two landmarks at critical instant (3.6B). The right shoulder medial rotation range of motion in this demonstration is estimated at 14.5°.

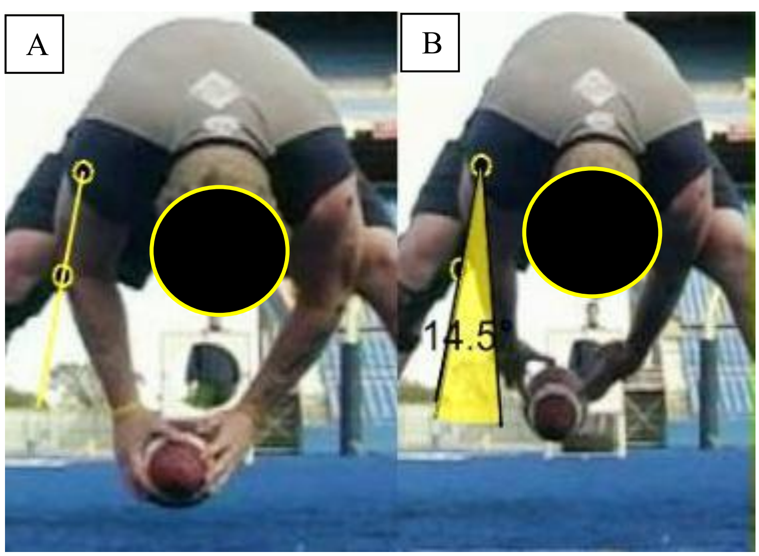


Figure 3.6: Illustration of arm/leg contact position (A) and critical instant (B) used to estimate shoulder medial rotation (14.5° shown) in the long snap.

The estimation of pronation at the forearm (proximal and distal radio-ulnar joints) was done by using the same line (only now extended) down the lateral border of the humerus and passing over the lateral humeral epicondyle (Figure 3.7A) at arm/leg contact. This line served as the baseline measure. A second line was then drawn from the lateral humeral epicondyle to the radial styloid process. The angular difference between the two lines when viewed from the front will represent the estimate of forearm pronation. The same landmarks will be used to measure the angle at critical instant (Figure 3.7B) and the difference between the angles was used to represent the estimation of forearm pronation.

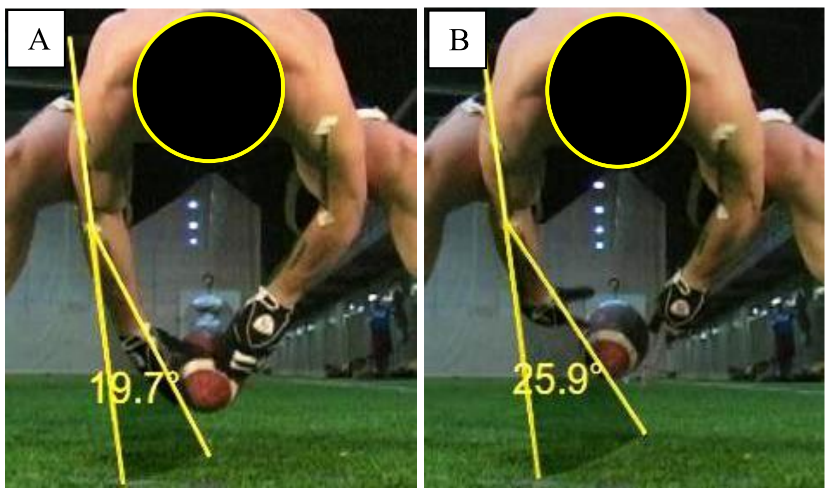


Figure 3.7: Illustration of the angles created by the lateral humerus extended and the radial styloid process at arm/leg contact position (A) and at critical instant (B) used to estimate forearm pronation (6.2° ROM in the image) during the long snap.

Distance measures were conducted throughout the analysis: stance width, right and left heel distance from the line of scrimmage, and horizontal distance covered by the athlete when airborne. These were accomplished by using an object with a known size (the study used a 1m reference marker), and then using that measure as a distance reference. Subsequent line segments from a similar plane within the image could then be measured accurately (to within 0.01 m). Figure 3.8 shows an example of this measurement tool.

This allowed for the measure of stance width, from left instep to right instep, shown here as 1.19 meters, with the black and yellow line representing the known distance reference.

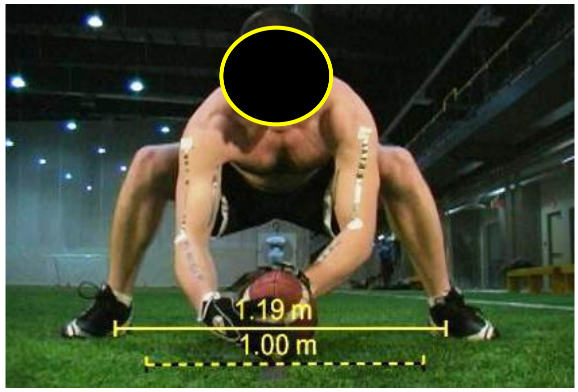


Figure 3.8: Example of distance measures in Dartfish video analysis software.

It was possible to produce linear velocity measurements by employing the Data table function in the Analyzer mode of Dartfish. The data table allowed the researcher to mark an object in two separate frames, while the software calculated the linear velocity of the object over those two frames. Figure 3.9 shows a data table where the Timecode tells us that we are calculating the velocity of the football over a 0.067 (0.834-0.767) second time interval. Data refers to the x and y co-ordinates of the two markers. In this case, the trailing tip of the football was used as the point of reference. The linear velocity over that specific time interval is titled “Interval speed”, and in this case is 15.17 m/s.

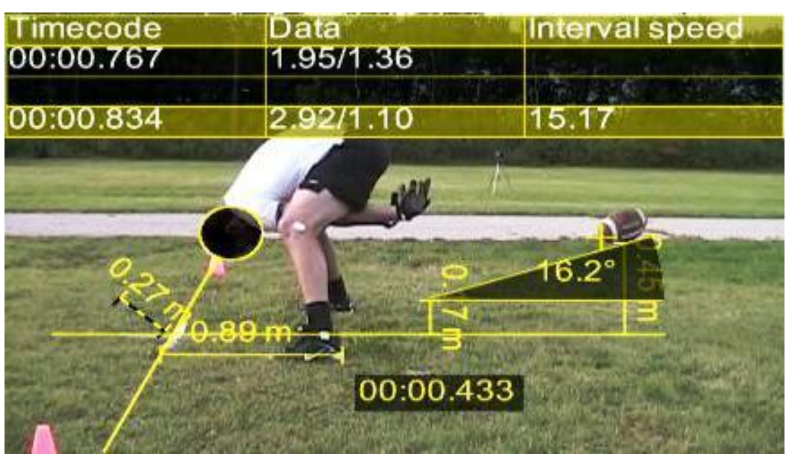


Figure 3.9: Sample of data table for calculating long snap release velocity.

Another interesting measure was the position of maximum trunk or spinal flexion. The line of the trunk is often made from the centre of the shoulder joint to the centre of the hip joint as seen Figure 3.5, but this does not recognize the flexion occurring at individual vertebrae. To include this spinal flexion a method for measuring spinal flexion was devised. Dartfish has a Spline tool which allows the user to mark multiple points along a curve, and the software will connect the points with a curved line (Figure 3.10). The greatest distance from spline to straight line could then be measured (yellow arrow), and was labelled as maximum spinal flexion.

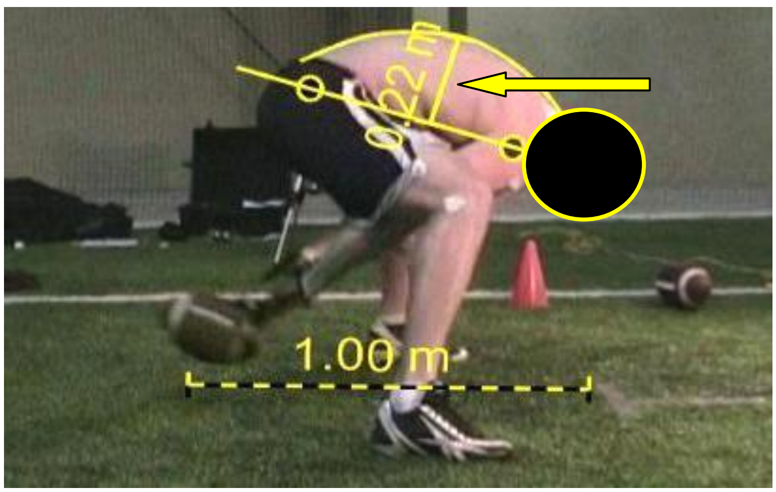


Figure 3.10: Illustration of how maximum spinal flexion was measured in the study. This trial would measure 0.22m of maximum spinal flexion.

Average angular velocities of the joints were calculated by using the joint angle measuring tool and time code function in Dartfish. By measuring the angular displacement of a given joint over time (between the backswing and critical instant for example), it was possible to calculate average angular velocity in degrees per second that occurs during force production. Angular velocity and angular momentum of the football were measured by using the wide sagittal camera angle, which films the football during the entire flight. This allowed the researcher to count the revolutions of the football over the time in the air, and calculate the average angular velocity. The angular momentum (H) was then measured by multiplying the moment of inertia (I) of the football by the angular velocity (ω).

Statistical analyses

Reliability test

A reliability test was conducted during the data analysis to verify the precision and consistency of the measurements made by the researcher. The test consisted of choosing ten variables which included a combination of angle, distance, and velocity measures. The ten chosen variables were measured on a single subject in one sitting, and were then re-measured on five separate occasions over a five week time frame. The measurements from each session were recorded separately, and maintained on separate spreadsheets to limit researcher bias. Once all data had been collected for the reliability test, the results from each week were compiled to a master table and analyzed for reliability.

The reliability of the researcher's measures was determined by calculating the coefficient of variation for the ten variables. The coefficient of variation, also known as "relative variability", can be used to compare the variability of data with different means (Rockette, 2007). It is given as a ratio which explains how close repeated trials are to one another. It is calculated by dividing the standard deviation for the sample by the sample mean and can be expressed either as a fraction or a percent. This provided the researcher with a representation of the error in the multiple measurements.

An advantage of reporting the coefficient of variation is that it allows the researcher to compare variables that are expressed in different units, and still compare the scatter of these variables on a similar scale. The coefficient of variation and the precision of the researcher are inversely related, meaning a lower percentage indicates a higher precision of measurements by the researcher. The coefficient of variation is particularly useful for representing the reliability of athletic events or performance tests (Hopkins, 2000); and will allow the re-test reliability of the researcher to be reported. For most events and tests, the coefficient of variation is acceptable between 1% and 5% (Hopkins, 2000), depending on the nature of the event or test, the time between tests, and the experience of the tester.

Statistical tests

The selection of the independent variables was based on previous research studies (Blegen et al, 2005, Harrington, 2003, & Henrici, 1967) as well as information gathered in the pilot study and pre-pilot filming. The dependent variable for this study is the release velocity of the football. The fastest trials were identified first, with the most accurate being selected for analysis. From the completed measurements for each athlete, group means and standard deviations were calculated for the subjects' variables in the high school and university groups. The data was analyzed using SPSS 16.0.2 and Microsoft Excel 2003.

The mean variables for the two groups of subjects were compared using multiple independent *t*-tests to determine where significant differences existed between the high school and university groups. The *t*-test evaluates whether the means of two groups are statistically different from one another. A p-value ≤ 0.05 is the statistical norm. This indicates that the investigator understands and accepts that a 5% chance of committing a type I (α) error exists. A type I error occurs when the investigator is misled by the sample evidence into rejecting the null hypothesis when it is in fact true (Hassard, 1991). Due to the high number of *t*-tests being conducted, a false discovery rate (FDR) adjustment

(Benjamini & Yekutieli, 2001) was employed to determine a new p-value of 0.0105. By decreasing the p-value, the comparisons would be more stringent in determining significant differences, and the researcher would also run less risk of committing a Type I error.

Following the t-test comparisons, a Pearson product moment correlation analysis was completed. This test was conducted to determine specific relationships occurring between the variables within the movement and the release velocity of the subjects. The level of significance was set for the study at $p \leq 0.05$. Pearson's correlation reflects the degree of linear relationship between two compared variables, and ranges from +1 to -1. A correlation of +1 means that there is a perfect positive linear relationship between variables, while a -1 correlation means that there is a perfect negative linear relationship between variables. A correlation of 0 means there is no linear relationship between the two variables. Each of the independent variables will be correlated with the release velocity to determine those most closely related.

A forward stepwise multiple regression analysis was also completed in order to determine the level to which the independent variables may be significant predictors of release velocity. Stepwise (forward and backward) multiple regression is the instrument of choice when the researcher believes that several independent variables interact to predict the value of a single dependent variable (Hassard, 1991). The forward stepwise multiple regression analysis provides a list of variables that are considered to be significant contributors to the dependent variable (release velocity). During the first step, one variable is selected from the list of independent variables to determine the most significant predictor of velocity. All the remaining independent variables are then tested against the dependent variable to determine the next greatest contributing variable to release velocity. This process continues until the independent variables no longer provide a significant contribution to the dependent variable; an equation can then be produced showing all significant independent variables.

The forward stepwise multiple regression analysis was conducted on the high school and university groups separately in order to determine which variables are considered significant contributors to the velocity of the distance snap for each of the two groups tested. If the ranked list of predictor variables differs between the groups, this finding may suggest differences in long snapping technique between high school and university football players. The regression analysis was also conducted on all subjects (HS and UNI combined) in hopes of identifying velocity predictors for either skill level. By combining the groups, the researcher was hoping to address the possibility that some of the HS subjects were highly skilled, or the UNI subjects were not. A regression model for all snappers was able to utilize twice the data to locate relevant predictors of performance.

A fourth regression analysis was also conducted on all subjects to further isolate the most important biomechanical variables within the skill. Instead of predicting release velocity, this final analysis used total snap time (TST) as the dependent variable. This model included all subjects (HS + UNI) and release velocity was removed from the model altogether since it is such a strong predictor of TST.

Chapter 4

Results

This chapter outlines the measured differences that were found between high school and university football long snappers in the study. The results of the statistical analyses will assist in highlighting and discussing the factors suggested as being important in the long snap. Age, height and mass of the study subjects are presented in Table 4.1 below.

Table 4.1: Descriptive characteristics of subjects.

	High School Athletes N = 10		**University Athletes N = 10**	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**
Age (years)	17.10 ± 0.57	16-18	21.30 ± 1.49	19-24
Height (m)	1.82 ± 0.079	1.68-1.93	1.85 ± 0.076	1.70-1.98
Mass (kg)	88.95 ± 14.55	63.50-104.33	100.15 ± 9.89	81.65-113.40

Reliability Test

The ten variables measured in the five trial reliability analysis had a coefficient of variance between 0.0048 and 0.055, indicating that there were no remarkable or significant variations in the measurement of these variables. For most events and tests, the coefficient of variation is acceptable between 1% (0.01) and 5% (0.05) (Hopkins, 2000). The results of the reliability test are shown in Table 4.2.

Table 4.2: Results of the reliability test.

Variable measured	Mean N = 5	SD	Min.	Max.	Range	Coefficient of Variance
Stance width (metres)	1.14	0.0055	1.13	1.14	0.01	0.0048
Right heel distance from LOS (metres)	0.86	0.0055	0.86	0.87	0.01	0.0063
Backswing right foot out-turn (degrees)	26.70	0.60	25.70	27.20	1.50	0.023
Backswing trunk flexion (degrees from horizontal)	12.06	0.22	11.80	12.40	0.60	0.018
Backswing right shoulder flexion (degrees)	129.40	1.68	128.10	131.40	3.30	0.013
Backswing right elbow flexion (degrees)	10.24	0.56	9.70	10.90	1.20	0.055
Backswing hip flexion (degrees)	161.90	2.70	157.80	164.40	6.60	0.017
Backswing knee flexion (degrees)	85.06	0.94	83.70	86.00	2.30	0.011
Release angle (degrees from horizontal)	16.36	0.35	16.00	16.90	0.90	0.021
Release velocity (metres/second)	16.03	0.40	15.49	16.46	0.97	0.025

Comparison of Means and Standard Deviations for High School and University Long Snappers

One of the primary purposes of the study was to determine the kinematic differences between high school and university long snapping technique. The following section describes the means and standard deviations of the kinematic variables for the two groups in the study as well as the results of the independent *t*-tests which were performed. This section is divided into the key phases of the skill which were highlighted in Chapter 3, beginning with the athlete's preliminary movements and highlighting each successive position.

Preliminary Movements

During the preliminary movements of the long snap, eight variables were measured. These variables, along with the means and standard deviations for both the high school and university groups are presented in Table 4.3. Based on an adjusted p-value of 0.0105, none of the eight measured variables were shown to be significantly different between groups.

Table 4.3: *t*-test comparison of means and standard deviations of the measured variables during the preliminary movement phase. Significance at $*p \leq 0.0105$.

Variable	**High School Athlete N = 10**		**University Athletes N = 10**			
	Mean	**SD**	**Mean**	**SD**	**t-value**	**p-value**
Hamstring flexibility (0,1,2,3)	1.80	1.03	2.50	0.71	-1.77	0.09
Stance width (metres)	0.97	0.18	1.08	0.12	-1.54	0.14
Stance width (% standing height)	53.86	11.69	58.25	7.33	-1.00	0.33
Right heel distance from LOS (metres)	0.85	0.11	0.85	0.10	-0.15	0.88
Left heel distance from LOS (metres)	0.84	0.09	0.86	0.09	-0.38	0.71
Distance from LOS (average in metres)	0.85	0.10	0.86	0.10	-0.26	0.80
Right foot out-turn (degrees from sagittal)	36.14	8.87	37.56	7.26	-0.39	0.70
Left foot out-turn (degrees from sagittal)	34.38	6.77	34.68	6.02	-0.11	0.92

Backswing

A total of eight variables were measured during the backswing phase of the long snap. Comparisons of the means and standard deviations for the measured variables during backswing are presented in Table 4.4. Based on the adjusted p-value of 0.0105, none of the eight measured variables were determined to be significantly different between groups.

Table 4.4: *t*-test comparison of means and standard deviations of the measured variables during the backswing phase. Significance at $^{*}p \leq 0.0105$.

Variable	High School Athletes N = 10		University Athletes N = 10			
	Mean	SD	Mean	SD	t-value	p-value
Trunk flexion (° from horizontal)	11.82	2.58	10.75	9.07	0.36	0.72
Right shoulder flexion (degrees)	119.96	7.71	119.14	15.44	0.15	0.88
Left shoulder flexion (degrees)	105.00	8.87	107.54	15.56	-0.45	0.66
Right elbow flexion (degrees)	37.68	13.53	34.99	8.87	0.53	0.61
Left elbow flexion (degrees)	41.66	18.88	40.78	11.82	0.13	0.90
Hip flexion (degrees)	158.67	6.30	159.93	7.57	-0.41	0.69
Knee flexion (degrees)	82.94	9.20	80.75	17.70	0.35	0.73
Ankle dorsiflexion (degrees)	-9.82	2.17	-8.49	2.12	-1.39	0.18

Force Production

During the force production phase of the long snap, a total of 37 variables were measured. Comparisons of all the means and standard deviations during force production are presented in Table 4.5, with three of the measured variables proving to be significantly different between the high school and university groups. The three significantly different variables were: maximum angle of left elbow flexion (prior to elbow extension), left elbow extension range of motion (given in degrees), and left elbow extension velocity (in degrees per second). The mean angle of maximum left elbow flexion for the high school group was 62.36°, while the university group demonstrated a significantly higher mean angle of maximum elbow flexion at 80.23°, shown graphically in Figure 4.1.

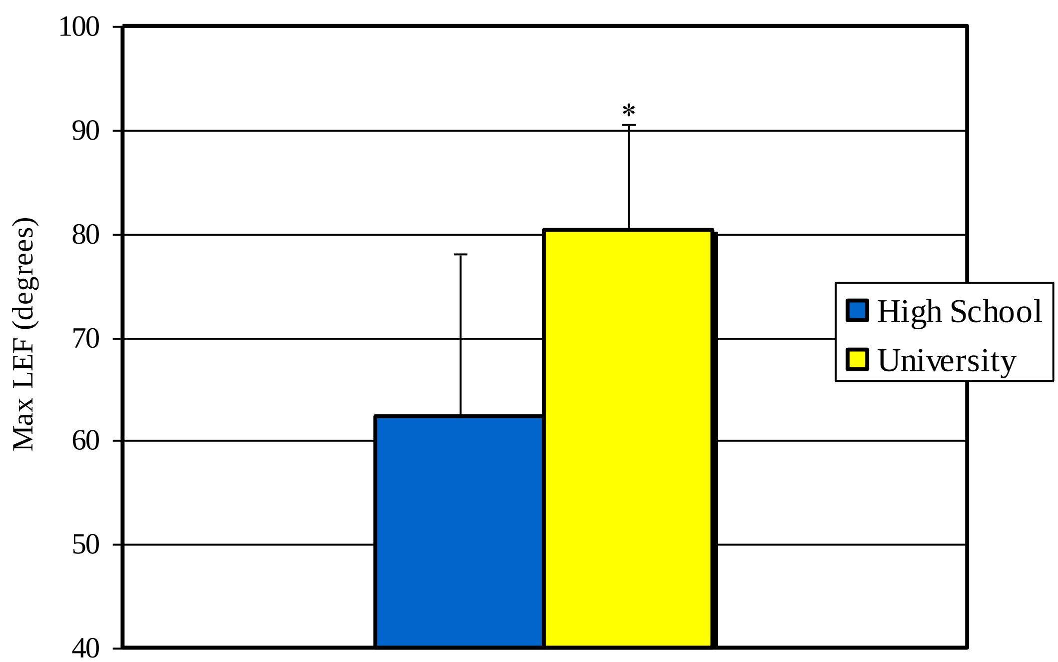


Figure 4.1: Comparison of the mean angles of maximum left elbow flexion (LEF) during force production indicating the significant difference between the groups ($*p \leq 0.0105$).

An example of the difference in position of maximum left elbow flexion for a high school and university long snapper is shown in Figure 4.2.

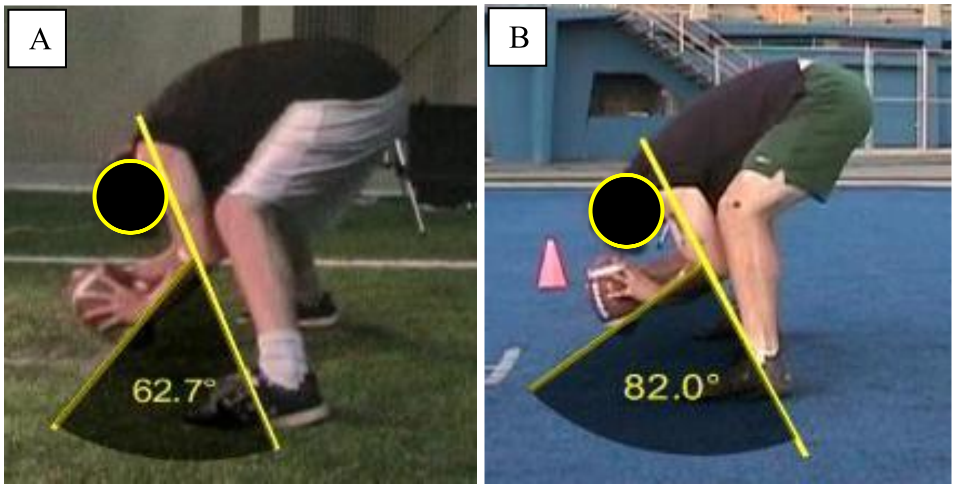


Figure 4.2: Example of a high school long snapper (A) and a university long snapper (B) in a position of maximum left elbow flexion just prior to elbow extension. University long snappers reach a position of greater left elbow flexion during the force production phase.

The increase in maximum left elbow flexion contributed to the university long snappers' release velocity as it also produced a significantly higher mean range of motion at the left elbow during elbow extension in the force production phase. While the high school group produced a mean range of motion of 46.61° at the left elbow, the university group recorded a mean range of motion of 67.93° (Figure 4.3). The difference between the two means was found to be significant with a calculated p-value of 0.00067. The final significant difference identified during the force production phase was the left elbow extension velocity. Not only did the university group extend their left elbow over a larger range of motion, but the angular velocity of extension was also significantly greater. Left elbow extension velocity for the high school group was measured to be 498.10°/s, while the university group was measured at 751.99°/s (Figure 4.4).

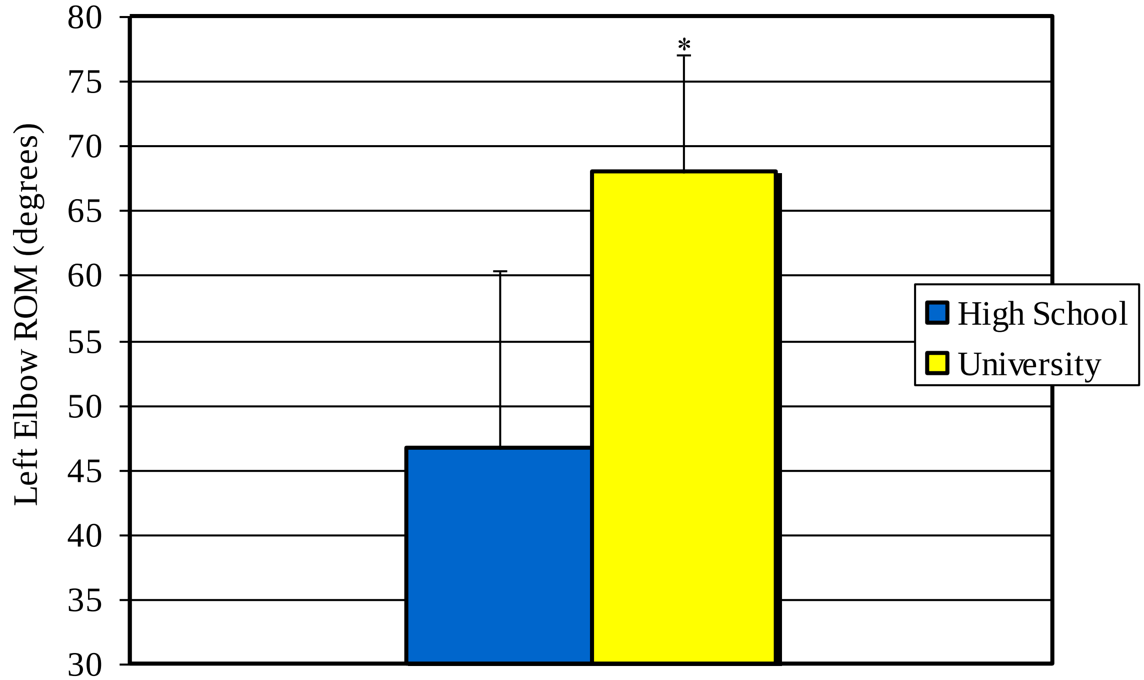


Figure 4.3: Comparison of the mean degrees (range of motion) of left elbow extension during force production indicating a significant difference between the groups (*p≤0.0105).

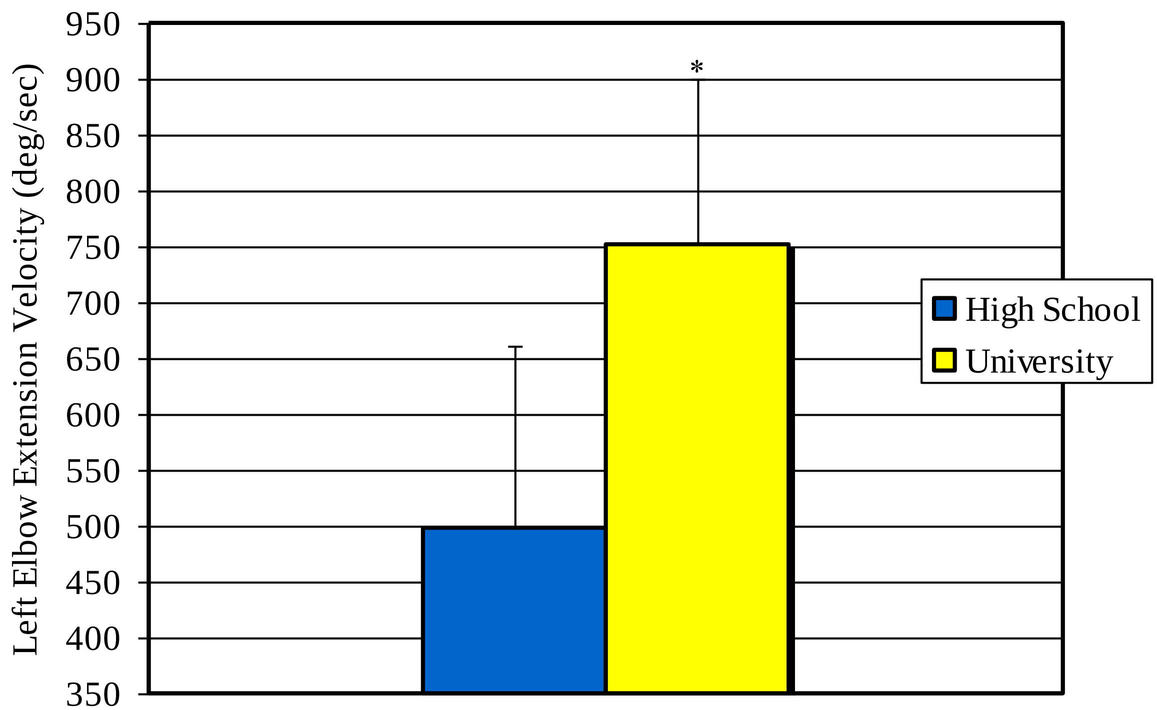


Figure 4.4: Comparison of the mean extension velocity at the left elbow during force production indicating the significant difference between the groups (*p≤0.0105).

Table 4.5: *t*-test comparison of means and standard deviations of the measured variables during the force production phase. Significance at *$p \leq 0.0105$.

Variable	High School Athletes N = 10 Mean	SD	University Athletes N = 10 Mean	SD	t-value	p-value
Max. right elbow flexion (degrees)	78.13	15.23	88.73	9.49	-1.87	0.078
Max. left elbow flexion (degrees)	62.36	15.77	80.23	10.25	-3.00	**0.0076***
Max. spinal flexion curve (metres)	0.20	0.022	0.21	0.026	-1.04	0.31
Right shoulder extension ROM (degrees)	72.32	10.94	68.26	19.10	0.58	0.57
Right shoulder extension velocity (deg/sec)	351.65	50.92	318.40	100.91	0.93	0.36
Left shoulder extension ROM (degrees)	60.35	10.15	56.55	15.00	0.66	0.52
Left shoulder extension velocity (deg/sec)	303.86	52.90	265.86	72.66	1.34	0.20
Right elbow extension ROM (degrees)	65.08	13.92	73.64	9.42	-1.61	0.12
Right elbow extension velocity (deg/sec)	685.17	176.03	797.50	135.92	-1.60	0.13
Left elbow extension ROM (degrees)	46.61	13.72	67.93	9.05	-4.10	**0.00067***
Left elbow extension velocity (deg/sec)	498.10	162.20	751.99	148.71	-3.65	**0.0018***
Hip extension ROM (degrees)	9.59	4.53	8.79	8.76	0.26	0.80

Table 4.5 continued	Mean	SD	Mean	SD	t-value	p-value
Hip extension velocity (deg/sec)	46.74	22.26	41.16	36.90	0.41	0.69
Knee extension ROM (degrees)	44.81	7.68	44.09	17.35	0.12	0.91
Knee extension velocity (deg/sec)	218.33	38.76	206.10	83.60	0.42	0.68
Ankle plantarflexion ROM (degrees)	20.84	6.12	17.19	4.11	1.57	0.13
Ankle plantarflexion velocity (deg/sec)	102.94	35.00	80.12	19.23	1.81	0.087
Right shoulder medial rotation ROM (degrees)	5.33	4.11	7.75	4.15	-1.31	0.21
Right shoulder medial rotation velocity (°/sec)	161.52	124.48	199.61	107.73	-0.73	0.47
Left shoulder medial rotation ROM (degrees)	7.23	7.30	7.37	3.81	-0.05	0.96
Left shoulder medial rotation velocity (°/sec)	219.09	221.33	191.29	106.46	0.36	0.72
Right forearm pronation ROM (degrees)	10.32	4.59	7.90	2.01	1.53	0.14
Right forearm pronation velocity (deg/sec)	312.73	139.22	211.27	54.96	2.14	0.046
Left forearm pronation ROM (degrees)	9.26	3.15	7.42	2.80	1.38	0.18
Left forearm pronation velocity (deg/sec)	280.61	95.40	196.10	88.62	2.05	0.055
Release time (seconds)	0.21	0.018	0.22	0.023	-0.90	0.38

Critical Instant

During the critical instant phase of the long snap, 25 variables were measured. Comparisons of the means and standard deviations for these variables at critical instant are presented in Table 4.6, with nine of the measured variables calculated to be significantly different between the high school and university groups. The nine significantly different variables were: right heel distance covered (metres), left heel distance covered (metres), total distance covered (average of both feet), total flight time of the ball (seconds), total snap time (release time + total flight time), release height of the football (metres), release height given as a percentage of standing height, release velocity of the football (m/s), and the average velocity of the football over 12.8 metres (m/s).

Table 4.6: *t*-test comparisons of means and standard deviations of the measured variables during the critical instant phase. Significance at *p≤0.0105.

Variable	High School Athletes N = 10		University Athletes N = 10			
	Mean	**SD**	**Mean**	**SD**	**t-value**	**p-value**
Total airborne time (seconds)	0.17	0.065	0.21	0.025	-1.81	0.087
Right heel distance covered (metres)	0.15	0.086	0.30	0.081	-3.85	**0.0011***
Left heel distance covered (metres)	0.17	0.097	0.29	0.082	-3.15	**0.0055***
Mean distance covered (average both feet) (m)	0.16	0.091	0.30	0.081	-3.53	**0.0024***
Total flight time of the football (seconds)	1.04	0.13	0.87	0.052	3.88	**0.0011***
Total snap time of the athlete (seconds)	1.25	0.13	1.08	0.060	3.51	**0.0025***

Table 4.6 continued	**Mean**	**SD**	**Mean**	**SD**	**t-value**	**p-value**
Release height of football (metres)	0.17	0.016	0.13	0.022	4.22	**0.00052***
Release height of football (as % of SH)	9.10	0.82	6.98	1.30	4.55	**0.00025***
Release velocity of ball (metres/second)	13.21	1.41	15.15	0.79	-3.78	**0.00069***
Release angle of ball (° from horizontal)	23.88	5.25	19.26	2.21	2.57	0.019
Average linear velocity of football (m/sec)	12.51	1.72	14.75	0.87	-3.69	**0.00083***
Average angular velocity of ball (deg/sec)	2301.34	369.93	2518.96	245.95	-1.55	0.14
Forward trunk lean (° from horizontal)	28.17	4.03	29.49	5.35	-0.62	0.54
Right shoulder flexion (degrees)	47.64	6.61	50.88	8.64	-0.94	0.36
Left shoulder flexion (degrees)	44.65	3.99	50.99	6.73	-2.56	0.02
Right elbow flexion (degrees)	13.05	6.33	15.09	2.88	-0.93	0.36
Left elbow flexion (degrees)	15.75	15.29	12.30	5.43	0.67	0.51
Right shoulder medial rotation ROM (degrees)	5.33	4.11	7.75	4.15	-1.31	0.21
Left shoulder medial rotation ROM (degrees)	7.23	7.30	7.37	3.81	-0.05	0.96
Right forearm pronation ROM (degrees)	10.32	4.59	7.59	2.22	1.69	0.11
Left forearm pronation ROM (degrees)	9.26	3.15	7.42	2.80	1.38	0.18
Hip flexion (degrees)	149.08	10.03	151.14	10.00	-0.46	0.65
Knee flexion (degrees)	38.13	12.98	36.66	17.59	0.21	0.83
Ankle plantarflexion (degrees)	11.02	6.26	8.70	4.04	0.98	0.34

The distance covered by the left heel, the right heel and the subsequent average distance of the two feet during the airborne phase of the long snap all proved to be significantly different between the high school and university groups. The high school group covered a mean distance of 0.15 m with the right heel while moving backwards during the airborne phase, while the university group produced a mean distance of 0.30 m covered by the right heel. This difference was calculated to be significant with a p-value of 0.0011 (Figure 4.5). The university long snappers also traveled a significantly greater distance with the left foot, showing a left heel mean horizontal displacement of 0.29 m, compared to the mean left heel displacement of 0.17 m demonstrated by the high school group. The subsequent average of the posterior horizontal displacement during the airborne phase for both feet was then calculated, and was found to be significantly different with a p-value of 0.0024 (Figure 4.5). The mean distance covered by both feet was 0.16 m in the high school group, and 0.295 m in the university group.

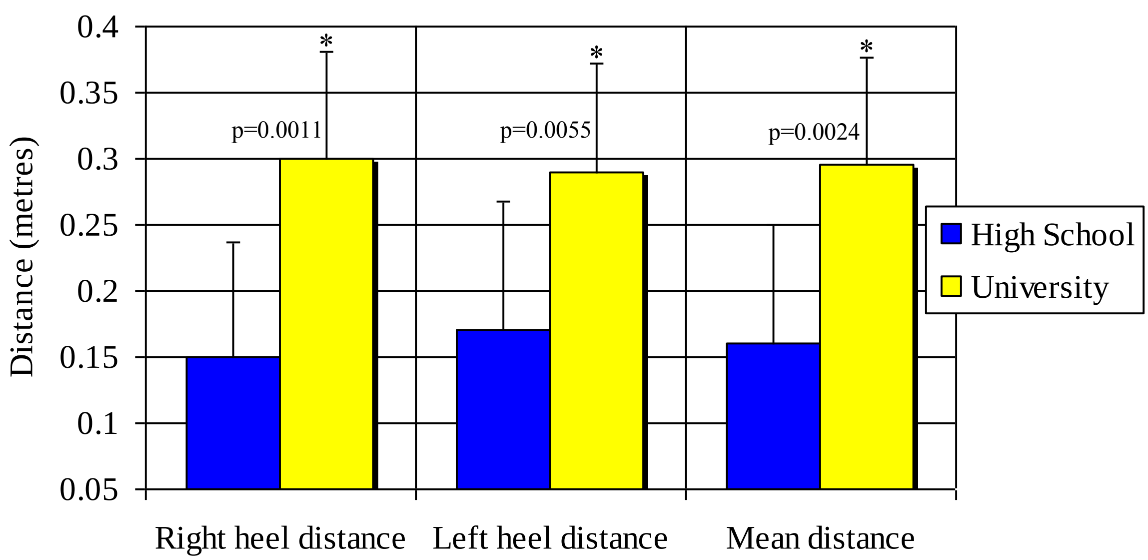


Figure 4.5: Comparison of the mean horizontal displacement of the feet during the airborne phase indicating the significant difference between the groups (*$p \leq 0.0105$).

Although the release time of the football from first movement to critical instant during force production was not shown to differ between the groups, the total flight time of the football as well as total snap time (release time + total flight time) did in fact prove to be significantly different. The high school group recorded a mean total flight time of 1.04 seconds, while the university athletes recorded a mean time of 0.87 seconds. This was a statistically significant difference with a p-value of 0.0011 (Figure 4.6). Once the release times were added to the total flight times for both groups, the total snap times also proved to be significantly different between high school and university athletes with a p-value of 0.0025 (Figure 4.6). The calculated mean total snap time (release time + total flight time of the football) was 1.25 seconds for the high school long snappers, while the university group demonstrated a mean total snap time that was significantly shorter at 1.08 seconds.

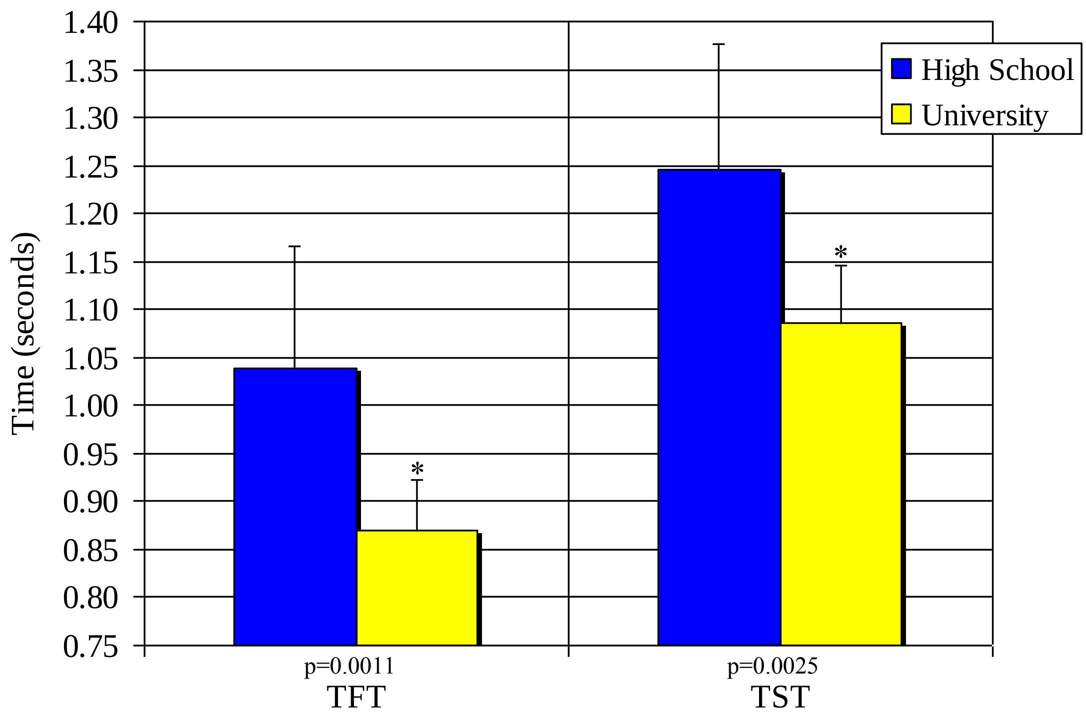


Figure 4.6: Comparison of the total flight time (TFT) and total snap time (TST) at the critical instant phase indicating the significant difference between the groups (*p≤0.0105).

Release height was found to be significantly different between the two groups with a p-value of 0.00052. The high school athletes released the football (measured from the football's lowest point at release) from a mean height of 0.17 m compared to a mean release height of 0.13 m for the university athletes. Figure 4.7 illustrates this difference between the two groups of subjects.

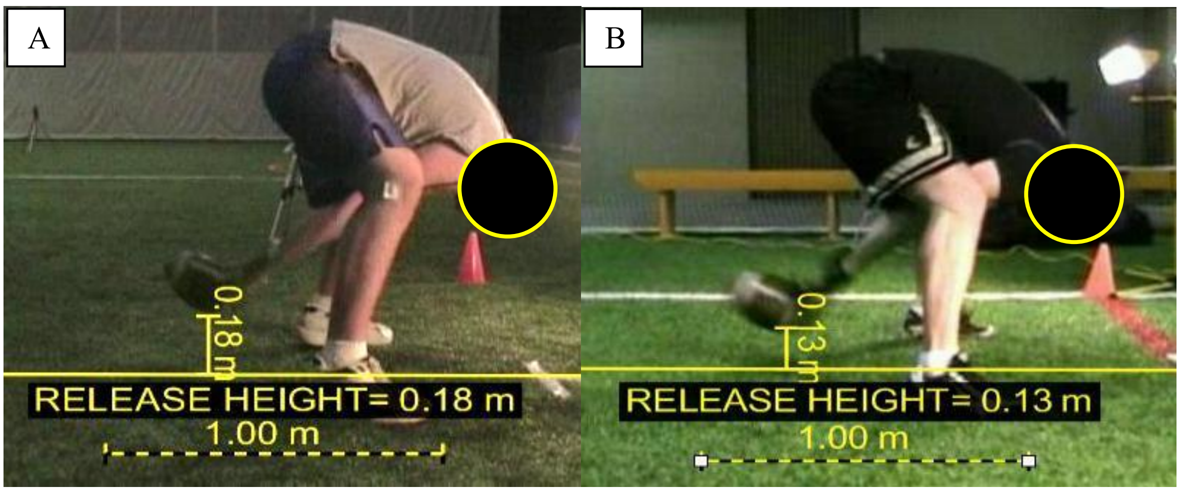


Figure 4.7: Example of a high school long snapper (A) and a university long snapper (B) at the moment of critical instant to measure release height. High school long snappers in the study demonstrated a significantly higher release height than university athletes.

Release height of the football was also calculated as a relative value reported as a percentage of the athlete's standing height (release height divided by standing height). Once the release height of the football was calculated as a percentage of height instead of an absolute distance measure, the difference between the high school and university groups became even more significant with a further decreased p-value of 0.00025 (Figure 4.8). The high school long snappers' mean release height was measured at 9.10% of their standing height, as compared to the university long snappers' mean release height which was measured at 6.98% of standing height.

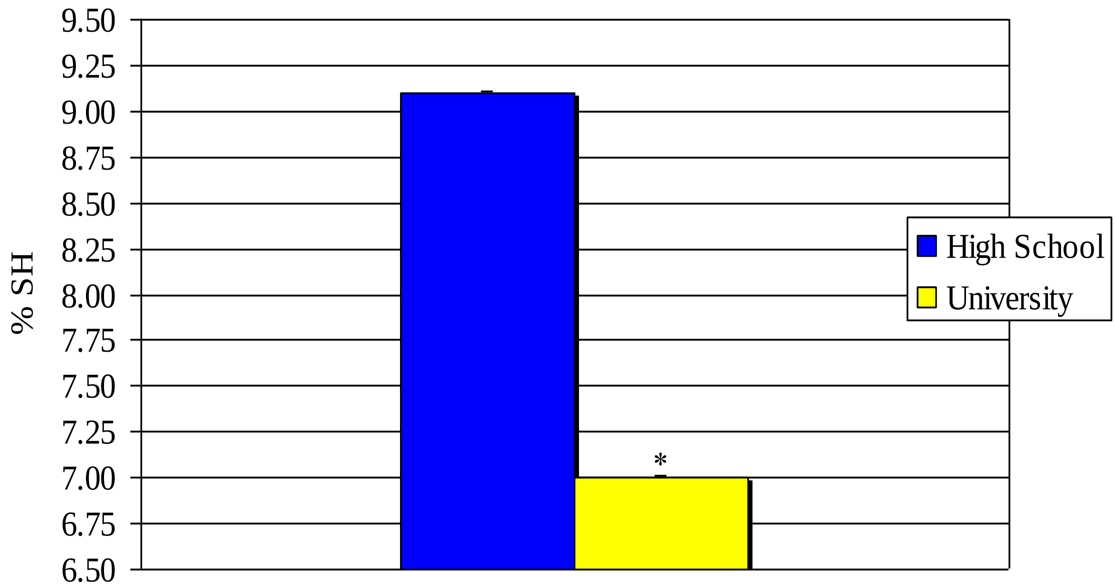


Figure 4.8: Comparison of the release height of the football at critical instant (reported as a percentage of the athlete's standing height) indicating the significant difference between the high school and university groups (*$p \leq 0.0105$).

When comparing the release velocity of the two groups (the dependent variable of the study), a significant difference was found in favor of the university athletes. The high school group demonstrated a mean release velocity of 13.21 m/s. The university group's mean release velocity was significantly faster at 15.15 m/s with a calculated p-value of 0.00069 (Figure 4.9). Due to the increased velocity of the football at release, the average horizontal velocity of the football (over the 12.8m distance) also showed a significant difference between the two groups. The high school long snappers had a mean average velocity of 12.51 m/s, while the university long snappers had a mean average velocity of 14.75 m/s. This measurement did not consider the trajectory of the football, only horizontal displacement over time. An interesting observation was that the high school subjects generally delivered the football with a higher or steeper angle of release (when measured from the horizontal). In fact, the difference between the release angles of both groups was almost significant with a p-value of 0.019 (Figure 4.10). The high school group released the football with a mean angle of 23.88° from the horizontal, while the university group released the football with a mean angle of 19.26°. This adjustment in the trajectory of delivery would allow a football delivered with less velocity to reach the punter at the appropriate height.

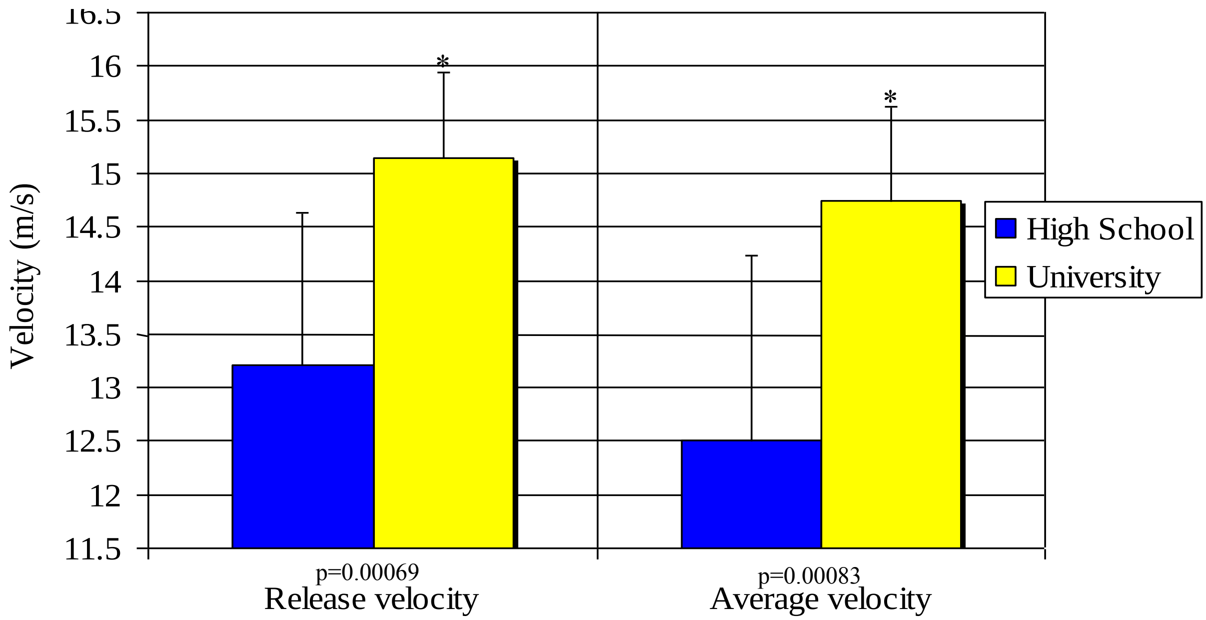


Figure 4.9: Comparison of the release velocity and average velocity of the football at critical instant indicating the significant difference between the groups (*p≤0.0105).

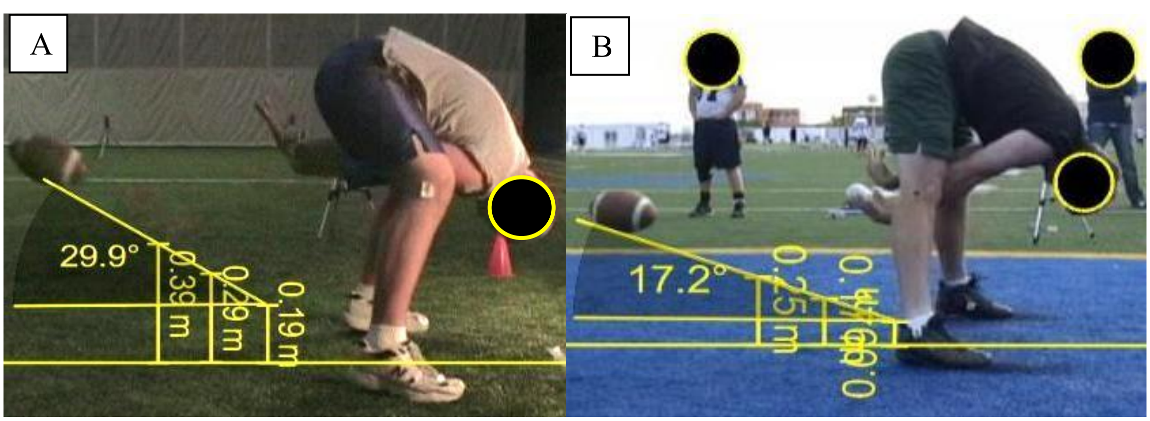


Figure 4.10: Illustration of a high school long snapper (A) and university long snapper (B) three frames after critical instant to measure release angle. High school subjects generally demonstrated a higher release angle than university athletes (not significant at p=0.019).

Follow Through

During the follow through phase of the long snap, five variables were measured. Means and standard deviations of these variables for both the high school and university groups are presented in Table 4.7. Based on an adjusted p-value of 0.0105, none of the five measured variables were shown to be significantly different between the two groups during the follow through.

Table 4.7: *t*-test comparisons of means and standard deviations of the measured variables during the follow through phase. Significance at $*p \leq 0.0105$.

Variable	**High School Athletes N = 10**		**University Athletes N = 10**			
	Mean	**SD**	**Mean**	**SD**	**t-value**	**p-value**
Forward trunk lean (° from horizontal)	33.01	5.80	34.27	5.80	-0.49	0.63
Right shoulder flexion (degrees)	33.17	4.61	37.31	7.69	-1.46	0.16
Left shoulder flexion (degrees)	35.95	5.22	38.73	4.63	-1.26	0.22
Hip flexion (degrees)	151.2	11.52	153.16	11.45	-0.38	0.71
Knee flexion (degrees)	38.74	11.18	36.5	15.63	0.37	0.72

Relationship of Kinematic Variables to Long Snapping Release Velocity

A sub purpose of the study was to determine which variables of those measured during the long snap were closely related to the football's release velocity. A Pearson's product moment correlation analysis was performed for both the high school and university groups to achieve this. The correlation analyses for the groups were performed separately in order to determine which variables for each skill level were significantly related to the release velocity of the football for the subjects involved.

High School Long Snappers' Correlation Analysis

The eight variables which had the strongest correlation to the high school group's long snapping release velocity are reported in Table 4.8. Six of these variables were found to be significant with a p-value ≤ 0.05. The other two variables presented were just outside the range of significance with p-values ≤ 0.06. The most highly correlated variables to long snapping release velocity in the high school group were (in order of significance): total snap time (release time + total flight time of the football), right elbow flexion in backswing, release height of the football given as a percentage of the athletes' standing height, release angle of the football measured from the horizontal, right forearm pronation range of motion during force production, left forearm pronation range of motion during force production, left elbow extension velocity during force production, and total horizontal distance covered backwards during the airborne phase occurring between force production and critical instant (average of both feet).

Table 4.8: Variables demonstrating the strongest correlation to long snap release velocity for the high school subjects.

	Correlation (High School Athletes) N=10	
Variable	r-value	p-value
Total snap time (seconds) (release time + total flight time of the football)	-0.915	**0.000201***
Right elbow flexion in backswing ready position (degrees)	-0.888	**0.000608***
Release height of the football (as a percentage of athlete's standing height)	-0.848	**0.00194***
Release angle of the football (measured from the horizontal)	-0.825	**0.00332***
Right forearm pronation ROM in force production (degrees)	-0.766	**0.00978***
Left forearm pronation ROM in force production (degrees)	-0.763	**0.0103***
Left elbow extension velocity in force production (degrees/second)	+0.623	0.0543
Distance covered during the airborne phase (average of both feet in metres)	+0.617	0.0574

The variable showing the highest correlation to release velocity of the football was total snap time. This variable is the sum of the release time (representative of the total time of force production) and the total flight time of the football to the punter. With a high negative correlation (-0.915), this suggests that the less time it takes for the ball to reach the punter from first movement of the long snapper, the higher the release velocity. This high correlation is entirely due to the fact that TST is strongly related to release velocity. The faster the ball is moving, the shorter the time it will take to reach the punter. Figure 4.11 shows the relationship of total snap time to release velocity.

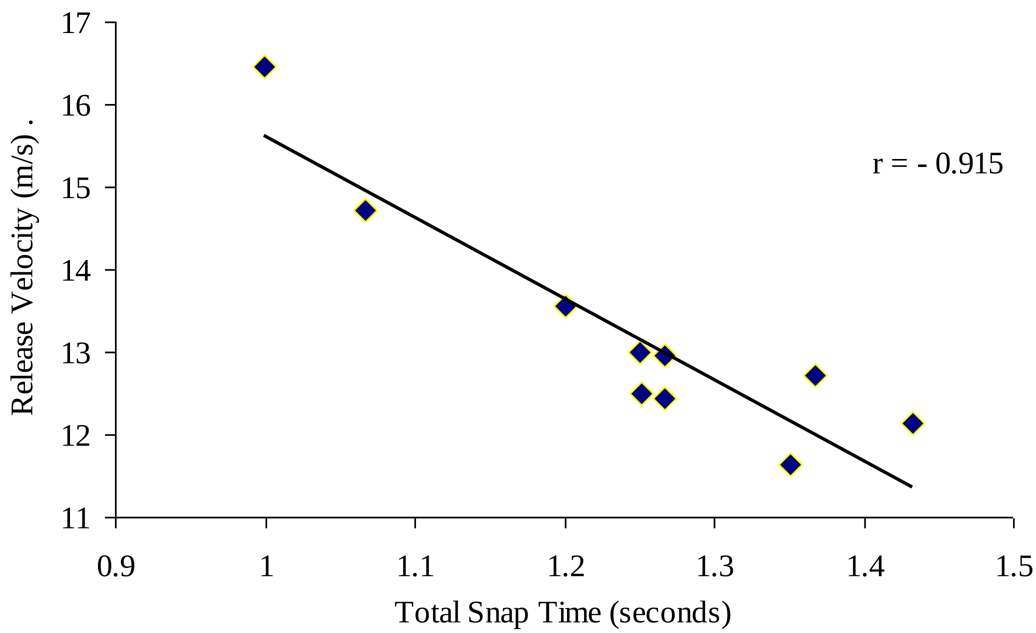


Figure 4.11: Relationship between high school long snapping release velocity and total snap time (release time + flight time of the football); where r = -0.915 and $p \leq 0.05$.

The angle of right elbow flexion in the backswing ready position was also shown to have a high negative correlation (-0.888) with the release velocity of the high school long snappers, indicating that less elbow flexion at this point of the skill was associated with greater velocity of the football at critical instant. Figure 4.12 represents this relationship graphically which was shown to be significant with a p-value of 0.000608.

Relative release height of the football (given as a percentage of the athlete's standing height) was also shown to have a strong negative correlation (-0.848) to release velocity. This indicates that the athletes who were able to achieve a higher release velocity were more successful at releasing the football from a lower height. Although absolute release height was also a strong correlation to release velocity (-0.685), once the measure was given as a percentage of standing height, the relationship was further amplified. The relationship of relative release height to release velocity is shown in Figure 4.13.

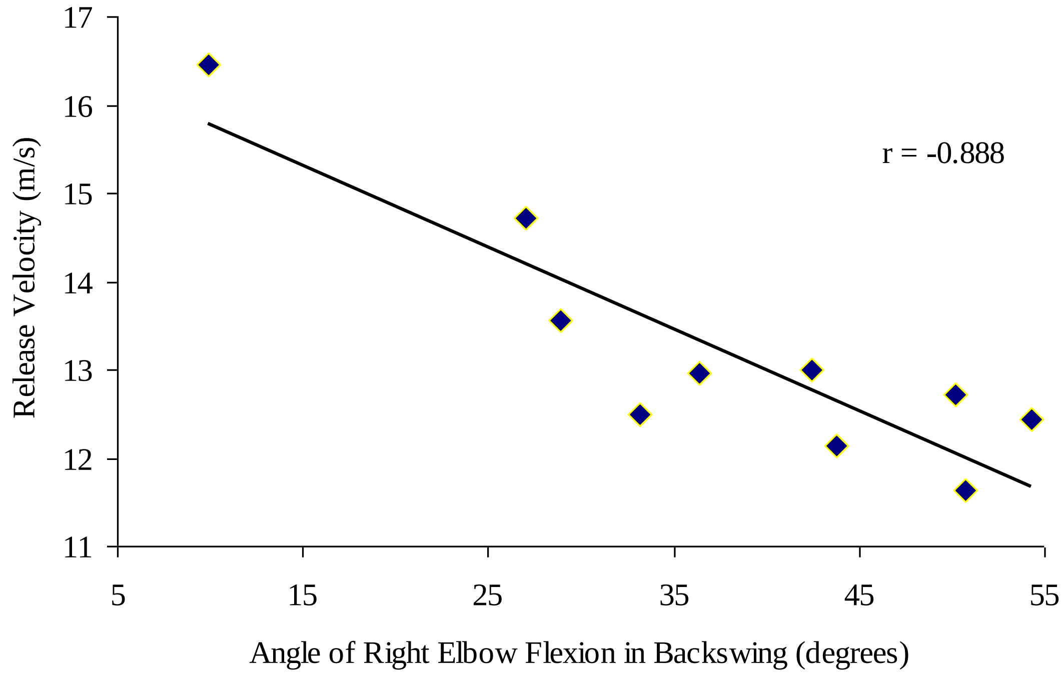


Figure 4.12: Relationship between high school long snapping release velocity and angle of right elbow flexion in the backswing ready position; where r = -0.888 and $p \leq 0.05$.

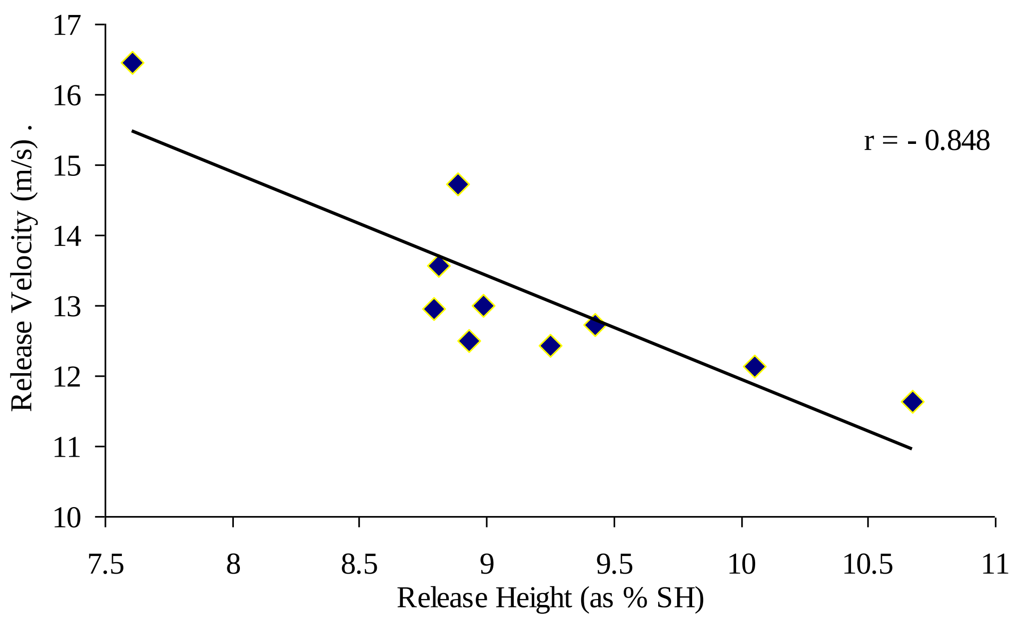


Figure 4.13: Relationship between high school long snapping release velocity and release height of the ball (as a % of athlete's standing height); where r = -0.848 and $p \leq 0.05$.

When correlated with release velocity, the release angle of the football also proved to be significant. With a p-value of 0.00332, the release angle (when measured from horizontal) had a correlation of -0.825 to the high school long snapper's release velocity. This indicates that high school long snappers with lower angles of release were shown to have greater velocity at release. A graphical representation of this relationship can be seen in Figure 4.14.

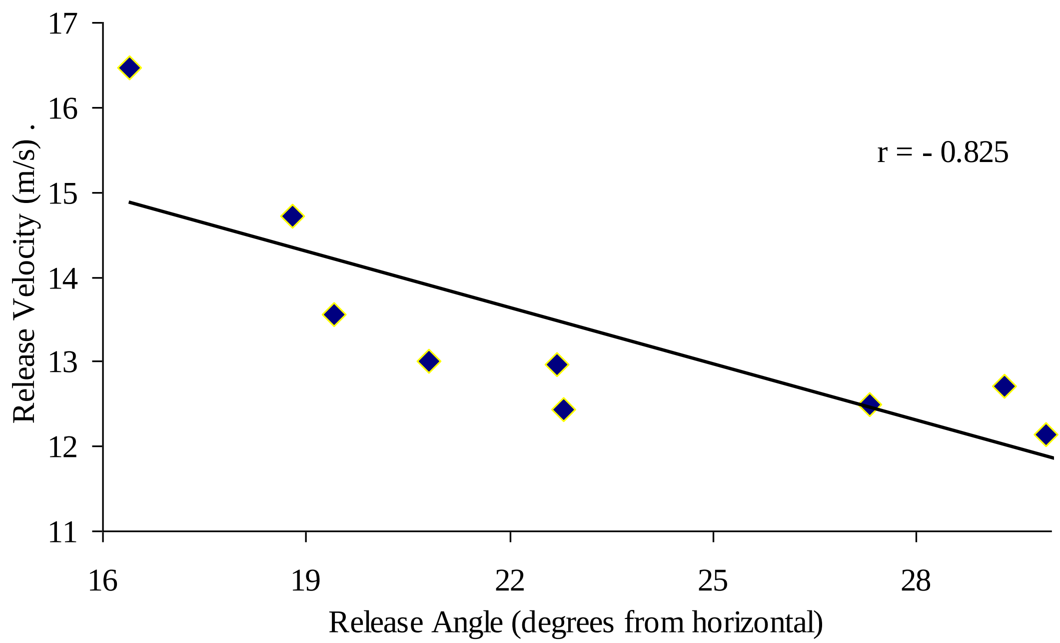


Figure 4.14: Relationship between high school long snapping release velocity and release angle of the football (measured from horizontal); where $r = -0.825$ and $p \leq 0.05$.

The final two variables which were shown to have a significant relationship with the high school subjects' release velocity were the range of motion of pronation in the right and left forearms (or proximal and distal radio-ulnar joints). The right forearm pronation range of motion was negatively correlated (-0.766) to release velocity with a significant p-value of 0.00978; while the left forearm pronation range of motion was also negatively correlated (-0.763) to release velocity with a nearly equally significant p-value of 0.0103. This suggests the high school athletes demonstrated higher release velocities when they went through lesser ranges of motion bilaterally at the proximal and distal radio-ulnar joints. The right hand relationship between pronation and release velocity is illustrated in Figure 4.15, while the left hand relationship is shown graphically in Figure 4.16.

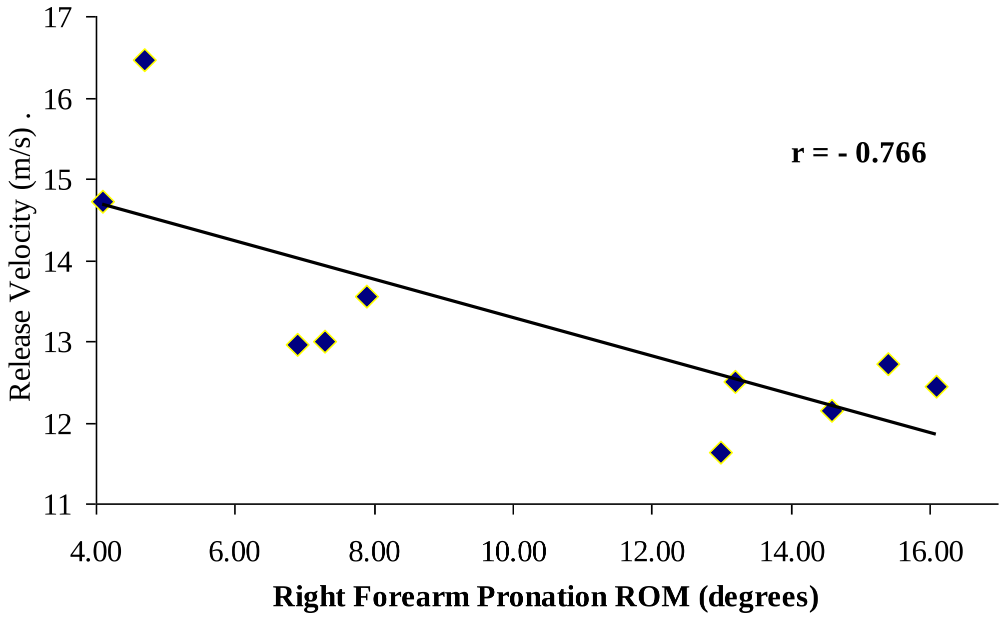


Figure 4.15: Relationship between high school long snapping release velocity and right forearm pronation range of motion; where r = -0.766 and $p \leq 0.05$.

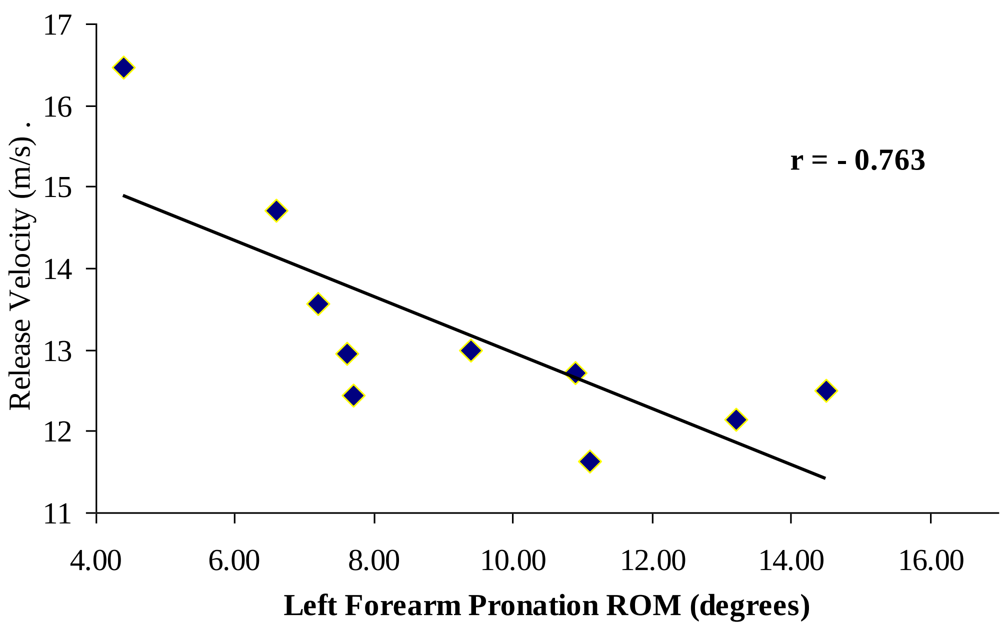


Figure 4.16: Relationship between high school long snapping release velocity and left forearm pronation range of motion; where r = -0.763 and $p \leq 0.05$.

Although not found to be significant, there were two interesting variables which came close to the 0.05 criterion with p-values ≤ 0.06. When comparing the high school group of subjects, left elbow extension velocity was found to have a strong positive correlation to release velocity (+0.623). This suggests that increased left elbow extension velocity may increase release velocity in the high school subjects. Backward distance covered by the feet during the airborne phase also had a strong positive correlation to release velocity (+0.617). This indicates that the athletes who moved further backward while delivering the football were able to achieve a higher velocity of the football at release.

University Long Snappers' Correlation Analysis

In Table 4.9, the eight variables which had the strongest correlation to the university group's long snapping release velocity are reported. Six of these variables were found to be significant with a p-value ≤ 0.05. The other two variables which will be presented were just outside the range of significance with p-values ≤ 0.08. The most highly correlated variables to university long snapping release velocity were (in order of significance): total snap time (release time + total flight time of the football), average angular velocity of the football during its flight (angular momentum), release angle of the football, maximum left elbow flexion prior to force production, right elbow extension range of motion during force production, maximum right elbow flexion prior to force production, right elbow flexion during the backswing ready position, and right elbow extension velocity during force production.

Table 4.9: Variables demonstrating the strongest correlation to long snapping release velocity for the university subjects; r-values and p-values are given for all variables.

	Correlation (University Athletes) N=10	
Variable	r-value	p-value
Total snap time (seconds) (release time + total flight time of the football)	-0.908	**0.000286***
Average angular velocity of the ball in flight (degrees/second)	+0.722	**0.0183***
Release angle of the football (measured from the horizontal)	-0.720	**0.0187***
Maximum left elbow flexion before force production (degrees)	+0.702	**0.0237***
Right elbow extension ROM in force production (degrees)	+0.670	**0.0340***
Maximum right elbow flexion before force production (degrees)	+0.633	**0.0495***
Right elbow flexion in backswing ready position (degrees)	-0.609	0.0614
Right elbow extension velocity in force production (degrees/second)	+0.584	0.0763

The variable which showed the highest correlation to the university long snappers' release velocity was the same highest correlated variable for the high school group, total snap time. This variable is the sum of the release time (representative of the total time of force production) and the total flight time of the football as it travels to the punter. With a high negative correlation (-0.908), this means the less time it takes for the football to reach the punter after first movement by the long snapper, the higher the release velocity. As with the high school group, this correlation is not particularly surprising, but further emphasizes the importance of keeping total snap time to a minimum in order to be a successful long snapper. Figure 4.17 illustrates the relationship of total snap time to release velocity.

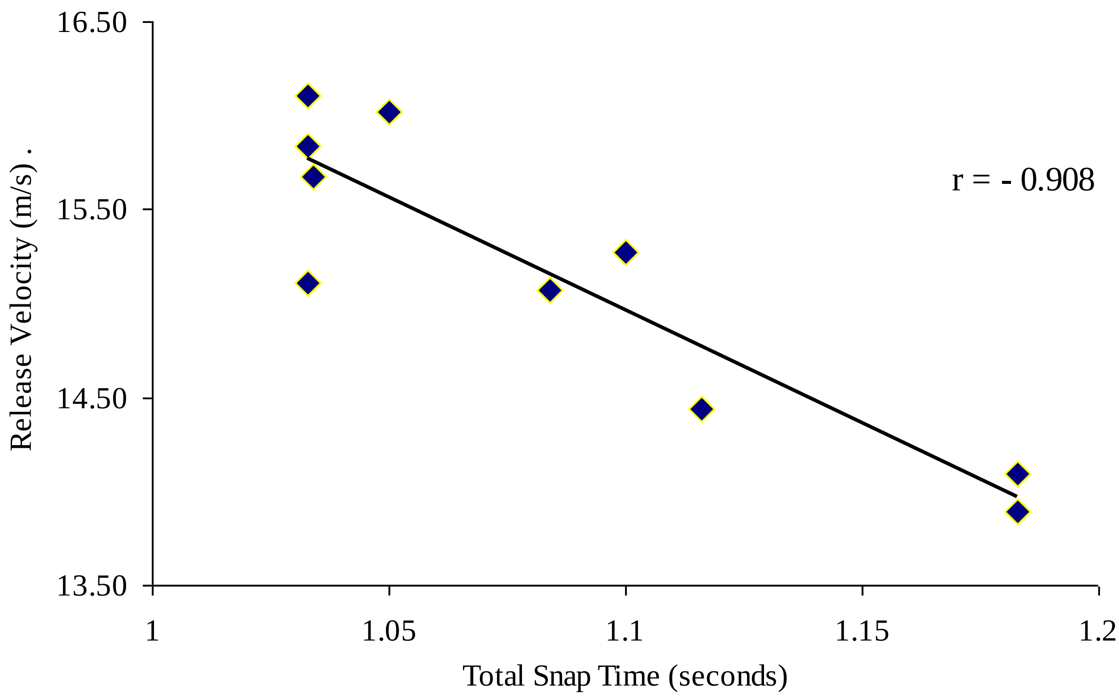


Figure 4.17: Relationship between university long snapping release velocity and total snap time (release time + flight time of the football); where r = -0.908 and $p \leq 0.05$.

The average angular velocity of the football in flight was also shown to have a high positive correlation (+0.722) with the release velocity of university long snappers. This correlation indicates that the greater the number of revolutions of the ball per unit time (speed of the spiral), the greater release velocity in this group. Figure 4.18 represents this relationship graphically which was shown to be significant with a p-value of 0.0183.

Another similarity to the high school group was shown when the university long snappers' release angle of the football was proven to be significantly correlated to release velocity. With a p-value of 0.0187, the release angle (when measured from horizontal) had a correlation of -0.720 to release velocity. This means that long snappers with lower angles of release were also shown to have greater velocity at release. A graphical representation of this relationship can be seen in Figure 4.19.

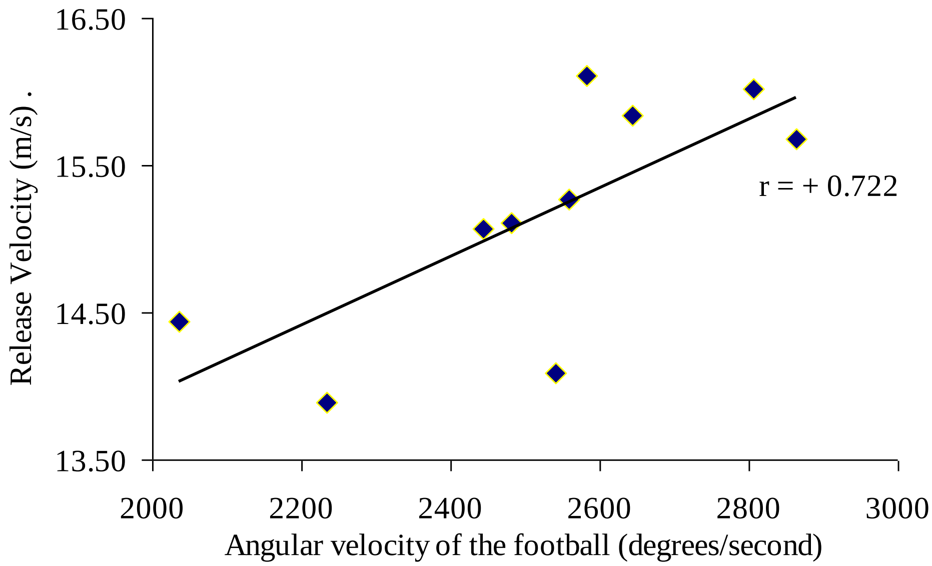


Figure 4.18: Relationship between university long snapping release velocity and angular velocity of the football during flight; where r = +0.722 and $p \leq 0.05$.

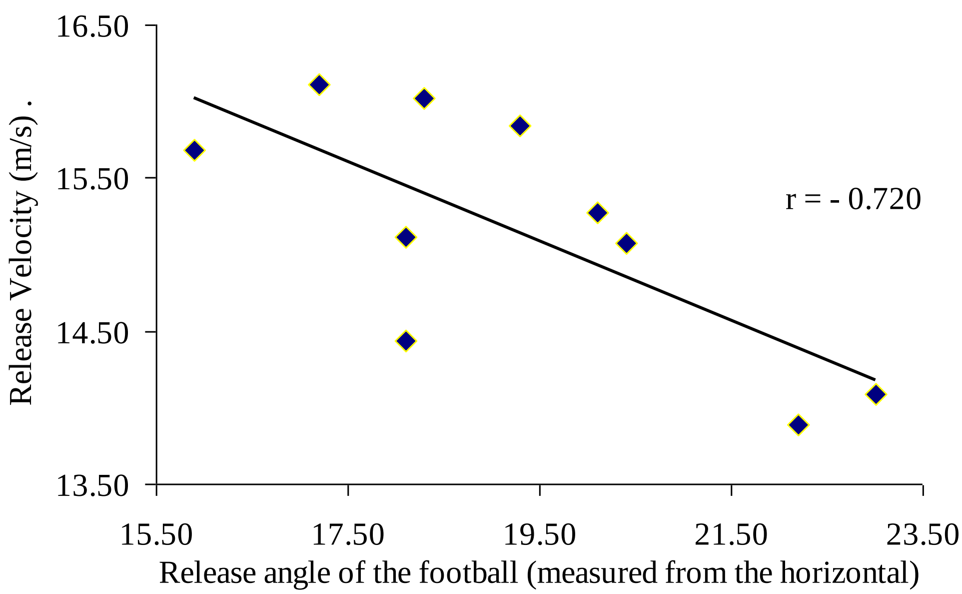


Figure 4.19: Relationship between university long snapping release velocity and release angle of the football at critical instant; where r = -0.720 and $p \leq 0.05$.

There were three more variables which showed significant correlation to release velocity in the university group. In order of significance, they were maximum left elbow flexion prior to elbow extension, right elbow extension velocity during force production and maximum right elbow flexion prior to elbow extension.

Maximum left and right elbow flexion angles will be presented together. Prior to force production at the elbows, greater elbow flexion angles in both arms was shown to be highly correlated to release velocity in the university group. Correlation of the maximum left elbow flexion angle (+0.702) was slightly higher than the relationship of the maximum right elbow flexion angle (+0.633); although both were significant with p-values of 0.0237 and 0.0495 respectively. The two variables and their relationship to release velocity are shown graphically in Figure 4.20.

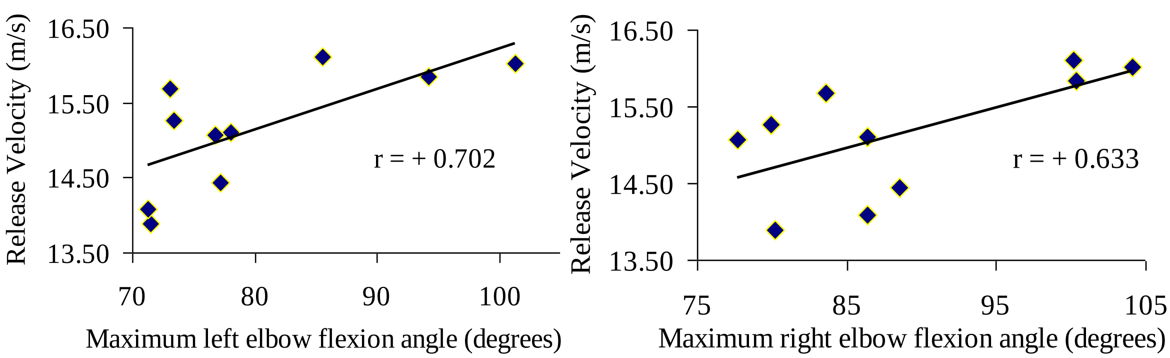


Figure 4.20: Relationship between university long snapping release velocity and maximum left and right elbow flexion; where r = +0.702 and +0.633 and $p \leq 0.05$.

The final variable which was shown to have a significant relationship with the university subjects' release velocity was the right elbow range of motion during extension. In order of significance, it ranked slightly higher than maximum angle of right elbow flexion with a correlation of +0.670 and a significant p-value of 0.0340. This means that the university long snappers who demonstrated a greater range of motion at the elbow during force production were able to demonstrate higher release velocities. The graphical representation of this relationship is shown in Figure 4.21.

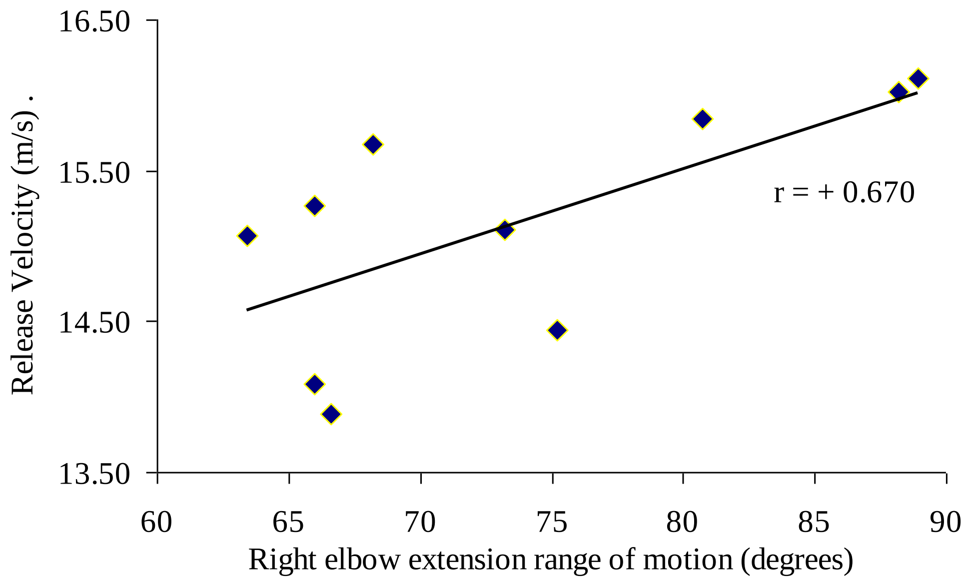


Figure 4.21: Relationship between university long snapping release velocity and right elbow extension range of motion in force production; where r = +0.670 and $p \leq 0.05$.

Although not proven to be significant, there were two interesting variables which came close to the 0.05 criterion with p-values ≤ 0.08. Between the university subjects, right elbow flexion angle in the backswing position was proven to have a strong negative correlation to release velocity (-0.609). This means that decreased flexion (or increased extension) in the right elbow at this phase was proven to increase release velocity in the university subjects. Right elbow extension velocity also had a noticeable correlation to release velocity (+0.584). This suggests that the athletes who were able to cover a greater angular displacement at the right elbow over a given unit time were able to achieve a higher velocity of the football at release.

Stepwise Multiple Regression Analysis

The final step of the statistical analysis was to perform three separate regression analyses and develop three separate models for predicting long snap release velocity (dependent variable): high school only, university only, and both groups combined. A fourth and final regression model was also developed to predict TST in all subjects without including release velocity as an independent variable. These analyses were conducted to develop regression models that might best explain the variation in skill performance, but also to identify the best predictors of successful long snaps. Within group correlations were also conducted with a correlation table inclusive of all variables. This was done to minimize the total number of variables entered in the regression equation. If two or more variables were highly correlated with each other, only one of them was considered for the regression equation in hopes of controlling the Type II error as much as possible. The risk of Type II errors increases with multiple comparisons, or when there is an increased risk of failing to reject the null hypothesis when it is false (Hassard, 1991). Variables were also combined whenever possible for the same reason. For example, the distances covered by the right and left feet when moving backwards were not entered individually, but instead the average was calculated as one variable representative of two measurements.

Regression Equation to Predict Release Velocity for High School Athletes

The stepwise multiple regression analysis of the high school long snappers returned a model with three predictors: total snap time, backswing hip flexion angle, and backswing knee flexion angle. Within the high school subjects, an r-squared value of 0.987 was returned for this model, which means that 98.7% of the variation in high school long snappers can be accounted for by this equation with these three independent variables. The variables are summarized in Table 4.10. Based on this model, the regression equation to predict release velocity in high school long snappers is presented in Figure 4.22.

Table 4.10: Summary of the variables selected by the stepwise multiple regression analysis for the predictor model of high school long snappers' release velocity.

Variables	Coefficient	Standard Error	Standardized Coefficient	t
Total Snap Time (seconds)	-11.350	0.537	-1.057	-21.143
Backswing Hip Flexion (°)	+0.150	0.020	0.667	7.416
Backswing Knee Flexion (°)	-0.057	0.013	-0.372	-4.275
Constant	+8.324	2.222		3.746

y = Dependent Variable = Release Velocity of the football (m/s)

Regression equation for high school athletes:

$y = +8.324 - 11.350x_1 + 0.150x_2 - 0.057x_3$

Where:

Intercept = +8.324

y = Release Velocity

X_1 = Total Snap Time (seconds)

X_2 = Backswing Hip Flexion (degrees)

X_3 = Backswing Knee Flexion (degrees)

Figure 4.22: Regression equation to predict high school long snapper release velocity.

In order to verify the multiple regression equation for the high school group, the appropriate values for three subjects were entered into the model. Subjects with low, high and mid-point release velocities were selected. The results of the prediction are reported in Table 4.11. This allowed the researcher to determine the ability of the regression equation to predict an individual high school long snapper's release velocity by comparing the result from the model to the recorded release velocity for that subject in the study.

Table 4.11: Predicted versus actual release velocities for three high school long snappers.

Variables	**Coefficients**	**HS3**	**HS4**	**HS5**
Total Snap Time (seconds)	-11.350	1.250	1.430	1.000
Backswing Hip Flexion (°)	+0.150	154.500	168.000	161.700
Backswing Knee Flexion (°)	-0.057	73.700	87.800	84.900
Intercept	+8.324	+8.324	+8.324	+8.324
Predicted Release Velocity (m/s)	N/A	**13.11**	**12.25**	**16.39**
Actual Release Velocity (m/s)	N/A	**13.00**	**12.14**	**16.46**

Regression Equation to Predict Release Velocity for University Athletes

The stepwise multiple regression analysis of the university long snappers returned a model with four predictors: total snap time, critical instant left shoulder flexion angle, maximum left elbow flexion angle, and release height as a percentage of standing height. Within the university subjects, an r-squared value of 0.928 was returned for this model, which means that 92.8% of the variation in university long snappers can be accounted for by this regression equation with these independent variables. Table 4.12 summarizes the four variables. Based on this model, the regression equation to predict release velocity in high school long snappers is presented in Figure 4.23.

Table 4.12: Summary of the variables selected by the stepwise multiple regression analysis for the predictor model of university long snappers' release velocity.

Variables	Coefficient	Standard Error	Standardized Coefficient	t
Total Snap Time (seconds)	-8.428	2.161	-0.636	-3.900
CI Left shoulder flexion (°)	-0.004	0.015	-0.037	-0.300
Max. Left Elbow Flexion (°)	+0.026	0.012	0.332	2.186
Release Height (as % SH)	-15.363	8.536	-0.245	-1.800
Constant	+23.530	3.013		7.810

y = Dependent Variable = Release velocity of the football (m/s)

Regression equation for university long snappers:

$y = +23.530 - 8.428x_1 - 0.004x_2 + 0.026x_3 - 15.363x_4$

Where:

Intercept = +23.530

y = Release Velocity

X_1 = Total Snap Time (seconds)

X_2 = Critical Instant Left Shoulder Flexion (degrees)

X_3 = Maximum Left Elbow Flexion (degrees)

X_4 = Release Height of ball (as % of Standing Height)

Figure 4.23: Regression equation to predict university long snapper release velocity.

In order to verify the multiple regression equation for the university group, the appropriate values for three subjects were entered into the model. Subjects with low, high and mid-point release velocities were selected. The results are reported in Table 4.13. This allowed the researcher to determine the ability of the regression equation to predict an individual university level long snapper's release velocity by comparing the result from the model to the recorded release velocity for that particular subject in the study.

Table 4.13: Predicted versus actual release velocities for three university long snappers.

Variables	Coefficients	UNI1	UNI2	UNI3
Total Snap Time (seconds)	-8.428	1.033	1.116	1.183
CI Left shoulder flexion (°)	-0.004	63.000	58.200	46.900
Max. Left Elbow Flexion (°)	+0.026	85.500	77.200	71.500
Release Height (as % SH)	-15.363	0.0670	0.066	0.089
Intercept	+23.530	+23.530	+23.530	+23.530
Predicted Release Velocity (m/s)	N/A	**15.76**	**14.88**	**13.86**
Actual Release Velocity (m/s)	N/A	**16.11**	**14.44**	**13.89**

Regression Equation to Predict Release Velocity for HS and UNI Groups Combined

A stepwise multiple regression analysis was performed for all subjects that returned a model with four predictors: total snap time, subject height, left elbow extension velocity in force production, and backswing right elbow flexion angle. When all subjects were considered, an r-squared value of 0.969 was returned for this model, which means that 96.9% of the variation in long snappers (whether high school or university level) can be accounted for by this regression equation with these independent variables. Table 4.14 summarizes the four variables. Based on this model, the regression equation to predict release velocity in high school and university long snappers is presented in Figure 4.24.

Table 4.14: Summary of the variables selected by the stepwise multiple regression analysis for a predictor model of long snappers' release velocity from HS & UNI groups combined.

Variables	Coefficient	Standard Error	Standardized Coefficient	T
Total Snap Time (seconds)	-8.201	0.859	-0.709	-9.550
Subject's Height (m)	+3.180	0.875	0.166	3.633
Left Elbow Extension ROM (°)	+0.022	0.005	0.228	4.024
Backswing Right Elbow Flexion (°)	-0.021	0.008	-0.160	-2.540
Constant	+17.438	1.878		9.286

y = Dependent Variable = Release velocity of the football (m/s)

Regression equation for HS and UNI long snappers:

$y = +17.438 - 8.201x_1 + 3.180x_2 + 0.022x_3 - 0.021x_4$

Where:

Intercept = +17.438

y = Release Velocity

X_1 = Total Snap Time (seconds)

X_2 = Subject's Height (m)

X_3 = Left Elbow Flexion Range of Motion (degrees)

X_4 = Backswing Right Elbow Flexion (°)

Figure 4.24: Regression equation to predict HS or UNI long snapper release velocity.

In order to verify the multiple regression equation for all subjects, the appropriate values for two subjects from each group were entered into the model. Random subjects who had not been previously verified were chosen for the comparison. The results of test score prediction are reported in Table 4.15. This allowed the researcher to determine the ability of the regression equation to predict the release velocity of an individual high school or university long snapper by comparing the result from the model to the recorded release velocity for that particular subject in the study.

Table 4.15: Predicted versus actual release velocities for 2 HS and 2 UNI long snappers.

Variables	**Coefficients**	**HS6**	**HS9**	**UNI8**	**UNI10**
Total Snap Time (seconds)	-8.201	1.267	1.251	1.100	1.050
Subject's Height (m)	+3.180	1.820	1.680	1.850	1.890
Left Elbow Extension ROM (°)	+0.022	30.300	34.000	66.100	84.900
BS Right Elbow Flexion (°)	-0.021	36.400	33.200	41.500	34.600
Intercept	+17.438	+17.438	+17.438	+17.438	+17.438
Predicted Release Velocity (m/s)	N/A	**12.74**	**12.57**	**14.88**	**15.98**
Actual Release Velocity (m/s)	N/A	**12.96**	**12.50**	**15.27**	**16.02**

Regression Equation to Predict TST for HS and UNI Groups Combined

A final regression analysis was performed for all subjects (HS + UNI) that returned a model with three predictors of TST (Table 4.16): release angle of the football, left elbow extension ROM, and right shoulder medial rotation ROM. With all subjects considered, an r-squared value of 0.924 was calculated, which means that 92.4% of the variation in a long snapper's TST (whether HS or UNI) can be accounted for by this equation. Based on this model, the regression equation to predict TST in high school and university long snappers is presented in Figure 4.25.

Table 4.16: Summary of the variables selected by the stepwise multiple regression analysis for a predictor model of long snappers' TST from HS & UNI groups combined.

Variables	Coefficient	Standard Error	Standardized Coefficient	T
Release Angle of Ball (°)	+0.023	0.002	0.799	10.806
L Elbow Extension ROM (°)	-0.003	0.001	-0.320	-4.195
R Shoulder Med. Rotation ROM (°)	+0.006	0.002	0.209	2.926
Constant	+0.787	0.066		11.851

y = Dependent Variable = Total Snap Time (TST in seconds)

TST Regression equation for HS and UNI long snappers:

$y = +0.787 + 0.023x_1 – 0.003x_2 + 0.006x_3$

Where:

Intercept = +0.787

y = TST

X_1 = Release Angle of Ball (°)

X_2 = Left Elbow Extension ROM (°)

X_3 = Right Shoulder Medial Rotation ROM (°)

Figure 4.25: Regression equation to predict HS or UNI long snapper TST.

In order to verify the TST regression equation (for all subjects), the appropriate values for two subjects from each group were entered into the model. The same subjects that were used for the HS + UNI release velocity model were chosen in order to compare the two HS + UNI models with similar subjects. The results of TST prediction are reported in Table 4.17. This comparison allowed the researcher to determine the ability of the regression equation to predict the TST of an individual high school or university long snapper by comparing the result from the model to the recorded TST for that particular subject in the study.

Table 4.17: Predicted versus actual TST for 2 HS and 2 UNI long snappers.

Variables	**Coefficients**	**HS6**	**HS9**	**UNI8**	**UNI10**
Release Angle of Football (°)	+0.023	22.70	27.30	20.10	18.30
L Elbow Extension ROM (°)	-0.003	30.30	34.00	66.10	84.90
R Shoulder Med. Rot. ROM (°)	+0.006	6.90	2.60	7.90	3.20
Intercept	+0.787	+0.787	+0.787	+0.787	+0.787
Predicted TST (sec)	N/A	**1.260**	**1.329**	**1.099**	**0.972**
Actual TST (sec)	N/A	**1.267**	**1.251**	**1.100**	**1.050**

Chapter 5

Discussion

Introduction

The long snap to the punter is a complex skill requiring accuracy and high velocity to be effective within the special teams unit of a football squad. The difficulty is increased by the upside down position of the upper body during delivery which limits lower body force contribution and decreases balance and stability. Further difficulty is added to performance by knowing that contact from the defensive player is imminent as soon as the skill is initiated, also by the intricate blocking duties required immediately following execution of the skill. When comparing high school to university level players, even the untrained eye will notice remarkable differences in the velocity, accuracy and trajectory of the football; although one may not be able to pinpoint actual differences in athlete movement because the skill takes less than three tenths of a second to perform. One of the primary purposes of this study was to determine the variations in performance between high school and university players and whether there are any significant differences between them. This study also set out to identify which kinematic variables had the strongest relationship to release velocity of the football within each of the two groups. It is important to identify specific variables that play a role in determining release velocity for long snappers to assist coaches in teaching the skill to beginners or in further improving the skill with intermediate or advanced long snappers. Another purpose of the study was to determine the most effective body movements and positions which may ultimately be able to predict the release velocity of long snaps in high school and university athletes. This knowledge will assist in early detection of movement errors in potential long snappers.

This study analyzed the preliminary movements and backswing position of the long snap, through force production to critical instant, as well as the follow through of the snap. Variables identified by previous studies or by pilot study examining the long snap were measured at key points of the long snap with Dartfish 4.5.2 video analysis software. Following the measurement of the variables, statistical analyses were performed to determine which variables differed between the high school and university groups. The statistical tests determined which variables were strongly correlated to the football's release velocity in each group. The best predictors of release velocity for each group were also determined, as well as the best predictors of release velocity and TST for all subjects.

Preliminary Movements

The preliminary movements for the long snap can be further broken down into stance and grip (Fracas and Marino, 1989). Although variations in the grip were discussed in the literature review, grip of the football was not considered in the variables of the study due to the large range of individual differences based on hand size, instruction, strength and comfort. The study focused on how the athlete set his feet when assuming the backswing position awaiting the signal to snap. The snapper assumes a stance wider than shoulder width apart (Figure 5.1) with the ball bisecting the snapper's body (Grindle, 1999).

Figure 5.1: Illustration of the long snap stance with feet wider than shoulder width apart.

The two groups of subjects in this study did not show significant kinematic differences between them when comparing preliminary movement variables. The study did help to quantify stance width rather than simply stating that the feet were wider than shoulder width apart. Absolute stance width means ranged from 0.97m (HS) to 1.08m (UNI), with relative mean measures ranging from 53.86 to 58.25% of the subjects' standing height. The absolute measured difference was nearing significance with a p-value of 0.14, while relative stance width differences became less significant (p=0.33). The results of this study suggest that long snappers stand with the feet approximately one metre apart (Figure 5.2) or at a relative distance of approximately 55% of the athlete's standing height.

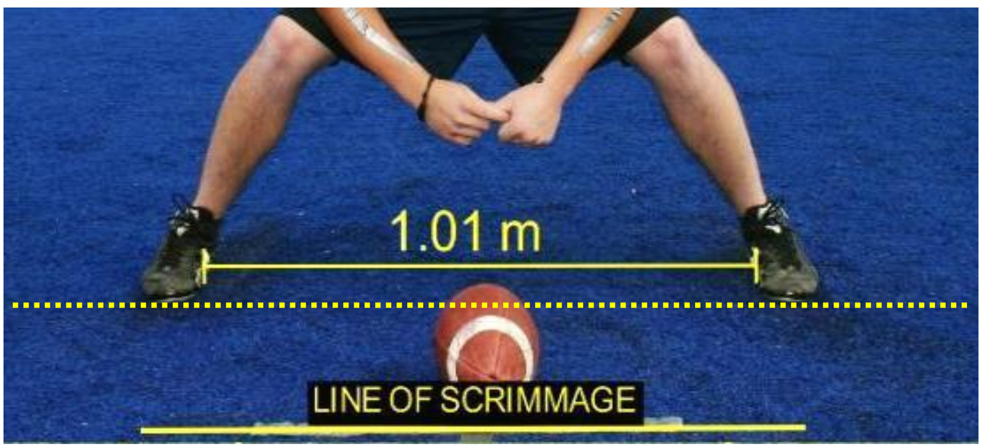


Figure 5.2: Illustration of recommended stance width showing a parallel foot placement.

A position that offers stability as well as range of motion in the lower body appears to be the compromise necessary in finding the ideal stance width. If the feet are too wide apart, the high degree of hip abduction may limit knee extension force contribution by limiting the range of motion possible at the knee. A stance that is too narrow may limit the range of motion at the shoulder and elbow in the backward direction, as well as limiting the summation of velocities of the arm, forearm, and hand segments (Fracas & Marino, 1989). Athletes should experiment with stance width in order to find their own balance of force production and stability through skill performance, using one metre as a guideline.

The player then chooses a parallel or non-parallel stance which refers to whether or not the feet are equidistant from the line of scrimmage or not. A parallel stance would mean the line of scrimmage is parallel to an imaginary line (dotted line in Figure 5.2) drawn from the toes of one foot to the other. A non-parallel stance would result when one foot is further from the line of scrimmage than the other. The feet are set in the preliminary stance position prior to gripping the football which has already been placed by the official with the forward tip of the football on the line of scrimmage, and the feet will not move again before snapping the football.

Difference in distance from the line of scrimmage between the study groups was negligible, with the average of the right and left heel distances being nearly identical at 0.85 m (HS) and 0.86 m (UNI). Catapano's (1998) research stated the athlete's toes should be 0.30 to 0.50 metres from the nearest tip of the football. The football measures up to 0.27 metres from tip to tip (Canadian Football League, 2008), and the distance between heel and toe of a size 10 shoe is 0.28 metres. When taking these distances into account, the study's measure of 0.86 metres would convert to an approximate distance of 0.31 metres between the toes and the nearest tip of the football, consistent with Catapano's findings. Although Ohton (1988) discussed the possibility of the non-parallel stance being beneficial in certain snapping situations, the subjects in this study demonstrated nearly perfectly parallel stances (Figure 5.2) consistent with Zauner's (1985) suggestion that the parallel stance is more advantageous. Particularly with the snap to punter, which covers the greatest distance of the three types of long snaps (12.8 m), a parallel stance would likely be the most beneficial setup for an accurate delivery where small deviations in lateral movement of the football at release may translate to large errors in accuracy.

Correlation Analysis

The preliminary movement variables did not prove to be significantly correlated to release velocity for either the high school or the university study groups. The highest correlation (r=-0.41) was found within the university subjects when relating absolute stance width to release velocity, which was not found to be significant with a p-value of 0.24. The relationship actually became even weaker as a relative value, with the relationship of stance width as a percent of standing height showing a correlation of -0.32 to release velocity.

Predictors of Release Velocity

Upon completion of the multiple regression analysis for all subjects combined, subject height was returned as a possible predictor and significant contributor to release velocity. Although this variable was categorized as a descriptive characteristic of the subjects and cannot be altered during performance, it will be discussed in this section of preliminary movements.

With all subjects combined, the height of the athlete had a coefficient of +3.180 in the HS & UNI regression model. Therefore, for every 10 cm increase in standing height, there may be a predictable 0.30 m/s increase in long snap release velocity. St. Leger (1989) made the suggestion that tall players make better snappers than short ones because short snappers have trouble with shoulder pads binding around the neck. St. Leger was referring to the setup position (backswing in the study) in which the shoulders are flexed from anatomical position and the ball is placed in front of the athlete. Taller athletes may be able to place the ball in front of them on the ground and flex the neck to look back at the punter without being as physically restricted by the shoulder pads as a shorter athlete.

Another possible reason for height being beneficial to increasing velocity is that taller individuals have longer limbs based on anthropometric measurements (Diffrient, Tilley, & Bardagjy, 1974). Since the long snapping motion restricts the use of the lower body (the feet remain planted) for force production, the shoulder and elbow extension movements provide much of the force that produces release velocity. With all other factors held constant, the greater the radius of rotation of a swinging lever, the greater the linear velocity of its end point will be (Hall, 2003). This can be demonstrated by the formula $V=r \bullet \omega$; where "V" is the linear velocity at any given point on a swinging lever, "r" is the radius or length from a point on the lever to the axis of rotation, and ω is the angular velocity of the lever. This relationship between lever length and linear velocity means that when comparing athletes who are able to produce similar angular velocities of the arm segments, the taller snapper with longer arms should be able to impart more linear velocity to the football at release.

Backswing

The backswing is the phase that places an athlete in position to generate force for the skill (Figure 5.3). The long snap has a unique backswing position since the athlete must essentially pre-set his body in an already loaded backswing position with nearly all of the movements from initiation of the snap occurring in the force producing direction.

Figure 5.3: Example of an athlete in the backswing position of the long snap.

Once the athlete is set, any movement by the long snapper means the defensive players are allowed to rush forward. This means the long snapper does not want to further flex the knees prior to their extension, since this will increase the release time of the football which increases total snap time and will increase the time defensive rushers have to attempt to block the punt. The elbows are an exception to this, and will flex to a maximal position as the shoulders extend during the first part of force production. This flexion of the elbows occurs to allow time for the knees to extend and provide the vertical clearance distance necessary for the subsequent maximum velocity elbow extension. Although there is some overlap of the backswing and force production phases in the discussion of the elbow, the backswing is the athlete's position of hip, knee, trunk and shoulder flexion, ankle dorsiflexion, elbow extension, left wrist extension, and right wrist flexion awaiting the signal to snap. In this position, the athlete is holding the ball on the ground with both hands in a comfortable and stable position (Zauner, 1985) with very little weight on the ball itself (Blegen et al, 2005).

When the kinematic variables from the high school (Figure 5.4) and university (Figure 5.5) subjects were compared during the backswing phase, no significant differences were found. Blegen et al (2005) found that increased angles of shoulder flexion and elbow extension were both significantly greater in the set (backswing) position for university level snappers when compared to high school snappers, though these findings were not replicated in this study. Backswing measures in this study in fact returned some of the highest p-values (minimal differences between the means of the groups) suggesting that high school and university long snappers do not differ in their set position prior to force production.

Figure 5.4: Side and front views of the backswing position in a high school long snapper.

Figure 5.5: Side and front views of the backswing position in a university long snapper.

Correlation Analysis

When the correlation analysis was completed for each group separately, one variable was returned as having a strong relationship to release velocity for both groups. Right elbow flexion angle in the backswing phase showed a significant negative correlation (r=-0.888) to release velocity in the high school group and a nearly significant negative relationship (r=-0.609) in the university group. This means that as the right elbow flexion angle decreases (or as the right elbow is further extended) in the set position, the release velocity tends to be higher. The right elbow flexion position in the backswing phase is illustrated in Figure 5.6 with an example of the flexion angle measured for two different subjects. By extending the right elbow more, the football can be placed further in front of the athlete, allowing for more time and a greater range of motion during force production. A similar relationship to limb placement in the set (backswing) position was found by Blegen et al (2005) who stated that by increasing elbow extension, "snappers lengthened the distance through which force could be applied to the ball during the preflight (force production) phase, thus, increasing the takeoff (release) velocity of the ball".

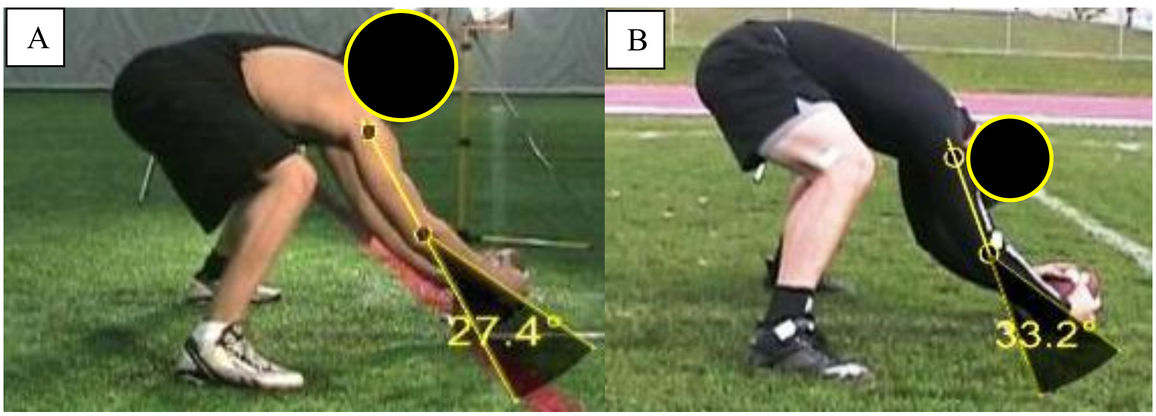


Figure 5.6: Decreased flexion of the right elbow in the backswing position is related to higher release velocity in both high school (A) and university (B) long snappers.

Predictors of Release Velocity

In the high school only stepwise regression model, two variables were selected from the backswing phase to predict release velocity (hip flexion angle and knee flexion angle). The regression analysis did not select any variables from the backswing for the university only group, but did return one variable to predict release velocity when both groups were combined (right elbow flexion).

Within the high school subjects, backswing hip and knee flexion were returned as possible predictors of release velocity. The hip flexion angle had a coefficient of +0.150 in the HS regression model. Therefore, for every five degree increase of hip flexion in the backswing phase, there would be a 0.75 m/s increase in long snap release velocity. The knee flexion angle had a coefficient of -0.057 in the model. This suggests that increased knee flexion may negatively affect release velocity in high school snappers.

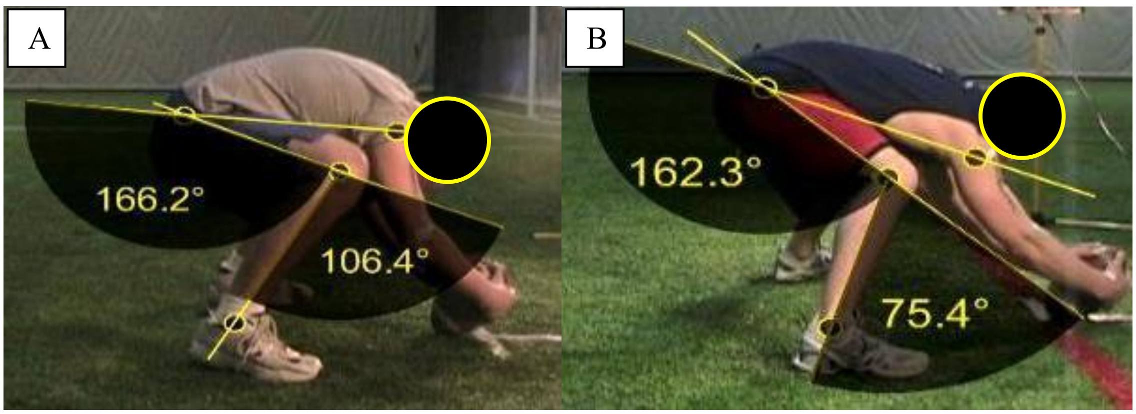


Figure 5.7: Along with higher hip flexion angles, decreased knee flexion is a possible predictor of higher release velocity in high school long snappers.

When in the long snap backswing position, the hands and feet are fixed to the ground (the hands through the ball). As previously discussed, it is beneficial to keep the ball further in front of the body for maximum range of motion through force production. A high degree of hip flexion makes this possible to do (along with a high degree of shoulder flexion and elbows extended). Greater knee flexion would inherently seem beneficial due to the lower body position. The problem in the long snap, in which the hands are fixed, is that with increased knee flexion the buttocks drop straight down making it more difficult to place the ball further in front of the body. Figure 5.7 illustrates this relationship of hip and knee flexion showing two separate high school subjects with similar hip flexion but varying degrees of knee flexion in the backswing. Notice the athlete on the left (A) has greater knee flexion which lowers the hips causing him to “sit down”. This negatively affects his shoulder flexion angle, making it more difficult to place the football further in front of the body. The athlete on the right (B) has less knee flexion with similar hip flexion, raising the buttocks in the air and allowing him to have greater shoulder flexion. The combination of these movements not only allows the long snapper to place the football further in front of the body, but increases the potential range of motion at the shoulder.

When both groups were considered, backswing right elbow flexion was chosen as a possible predictor of release velocity with a coefficient of -0.021 in the HS+UNI regression model. This means that for every five degree increase in elbow flexion, release velocity would be decreased by 0.1 m/s. Although this is a relatively small coefficient, in which small variations would produce minimal changes to release velocity, this variable’s inclusion reiterates the importance of extending the elbows and placing the ball on the ground further in front of the body. The study suggests that long snappers, whether competing at high school or university level, should consider decreasing the elbow flexion present in the right arm (Figure 5.6) with maximum release velocity as the objective.

Force Production

In one continuous motion, the force production phase of the long snap incorporates slight hip extension, with vigorous knee extension and ankle plantarflexion in the lower body (Figure 5.8). At the same time in the upper body, the trunk flexes and the shoulders extend over a large range of motion. The elbows first flex then extend with maximum velocity after the arms contact the legs, while the forearms pronate and the wrists flex and adduct bilaterally (also occurring after arm/leg contact). The appropriate muscles have to apply force in the correct amount, over the correct range and time period, and in the correct sequence (Carr, 1997). This must also be accomplished in one complete fluid motion for successful long snaps. Total time of force production in the snap is just over two tenths of a second (as measured in the study), further stressing the importance of fluidity and temporal sequencing of the skill.

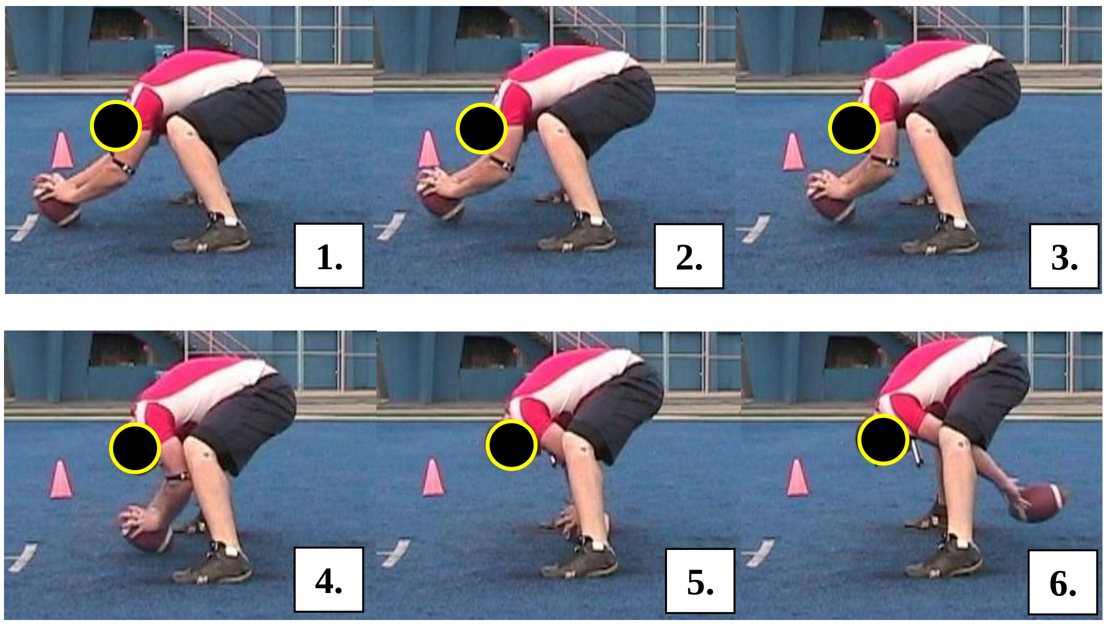


Figure 5.8: Sequential images of the force production phase in the long snap.

Maximum left elbow flexion

When the football is first lifted from the ground, the elbows will flex while the shoulders extend until the posterior distal upper arms contact the anterior medial portion of the thighs (Figure 5.8). The elbows then extend with maximum velocity contributing to the release velocity of the ball. When the maximum elbow flexion angle (prior to extension) during force production was compared between the groups, the university athletes showed significantly more flexion. The university group demonstrated a mean maximum elbow flexion angle of 80° while the high school group had a mean maximum elbow flexion angle of 62°. This difference is illustrated in Figure 5.9 and is a key factor in providing the university athletes with a greater range of motion at the elbow through which to exert force, since there was no difference in elbow flexion positions at critical instant. The formula to consider here is V=r•ω. The increased range of angular motion should result in an increased angular velocity (ω) provided the time frame and force production are relatively constant. The length of the lower arm (r) will also remain constant during the skill. The increased ω will translate to a greater linear velocity (V) at the hands, which will result in an increased release velocity of the ball. Provided the athletes are strong enough to maintain constant acceleration for the duration of the elbow extension, a greater range of motion (achieved by more elbow flexion) will result in a greater release velocity.

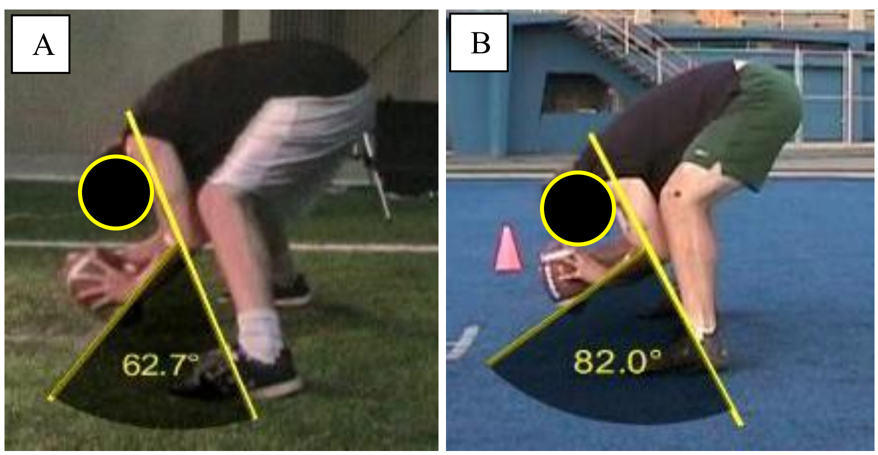


Figure 5.9: Example of a high school long snapper (A) and a university long snapper (B) in a position of maximum left elbow flexion just prior to elbow extension. University long snappers reach a position of greater left elbow flexion during the force production phase.

With the elbows nearly fully extended in the set position, the elbow extensors would only be capable of contributing minimally to force production. Unfortunately the recommended backswing position requires the long snapper to extend the elbows to place the ball further in front of the body. It is for this reason that the long snapper must flex the elbows first while the shoulders are initially extending in order to have a greater range of motion at the elbows through which to exert force. If the upper arm can rotate about the glenohumeral joint with a high enough velocity, it could cause the lower arm to "lag" (Chapman, 2008) behind in its rotation about the humeroulnar joint. This increased range of motion at the elbow may allow for a greater output from the contractile component of the muscle fibers for several possible reasons.

This greater output may be due to the athlete placing the triceps brachii closer to the optimal muscle length for the greatest contractile component. The contractile component is the actual tension development in a muscle enabled by stimulating the fibers via the nervous system (Hall, 2007). If the cross-bridge theory of skeletal muscle holds true, then the contractile response relies on the calcium ion (Ca^{2+}) to initiate the cycle by binding to various binding proteins, including troponin C, SERCA, and calmodulin among others (MacIntosh, Gardiner, & McComas, 2006). The signal for a contraction is the sudden increase of Ca^{2+} ions in close proximity to the myosin and actin filaments. Myosin, the thicker filament, has been described as having a globular head that spirals about the myosin filament in the region where actin and myosin overlap known as the A band (Nordin & Frankel, 2001). Recent high-powered electron microscopy with X-ray diffraction has revealed the myosin molecule consists of two globular heads and a single tail (MacIntosh et al, 2006). The long tail seems to be formed by two α-helices that coil round each other and associates with the tails of several hundred other myosin molecules to form a single myosin filament. "The cross-bridges are the globular heads of the myosin molecules" (MacIntosh et al, 2006). The interactions that take place between the myosin heads and actin filaments may be affected by the length of the muscle (amount of overlap of the cross-bridge area) or even the angle of the cross-bridge, and may be more or less effective because of this.

This means there may be a position in which flexion prior to elbow extension places the extensor muscles in the perfect overlap position to generate force. What is not known is the angle of elbow flexion required to be at the optimal position of filament overlap in the triceps brachii or even anconeus. The current study suggests that greater left elbow flexion prior to extension would improve release velocity. Before such a bold statement can be made, it now seems necessary to know at which length the elbow range of motion exceeds ideal filament cross-bridging. It may be found that elbow flexion past that point will result in decreased contractile force until that point is reached again, making flexion past that point a detriment to release velocity. This discussion is further complicated by the possibility that when the muscle is at its ideal length for contraction, the joint may be in such a position that the moment arm for the muscle force is decreased. This position of the joint may negate any advantage due to optimal filament overlap. It should be considered that although muscle force output is dependent on sarcomere length, the possible torque generation of the muscle depends on the angles of muscle insertions and length of moment arms about the joint of concern (MacIntosh et al, 2006).

This added range of motion that was seen in the UNI group prior to extension also elongates the triceps brachii muscles as the elbow goes into further flexion taking advantage of the elastic properties within the muscles and surrounding tissue. The elastic behaviour of muscle is described as consisting of two major components; the parallel elastic component (PEC) and the series elastic component (SEC) (Hall, 2007). The PEC is the elasticity provided by the muscle's connective tissue coverings such as epimysium, perimysium, endomysium and sarcolemma (Moore et al, 2010). These structures offer resistance when a muscle is passively stretched and recoil when contracted. The SEC, on the other hand, is the elastic component produced by the tendon of the muscle, and represents a spring-like elastic component working in series with the contractile component (Nordin & Frankel, 2001). These mechanical properties of the muscle and its tendon may be able to contribute to increased force production during elbow extension.

The elongation of the triceps may also cause the activation of the muscle to increase during the eccentric contraction phase prior to the concentric phase (Chapman, 2008), meaning the muscle can perform substantially more work when it contracts. Sometimes called the stretch-shorten or stretch-shortening cycle, this is a situation where the muscle undergoes a stretch (usually accompanied by an eccentric contraction) which is followed immediately by a concentric contraction resulting in an ultimately stronger contraction than if there had been no stretch prior to concentric contraction. This difference in muscle potential may be due to the calcium sensitivity in the muscle being altered by the proximity of the myosin head with the actin filament (which is affected by the length of the muscle). At longer sarcomere lengths, the myofilaments are closer together and Ca^{2+} sensitivity is increased in this condition (MacIntosh et al, 2006). An increase in Ca^{2+} sensitivity means that a greater force is obtained than what would have otherwise been predicted.

If the shoulders are able to extend quickly enough, forcing the elbows to flex to a greater extent due to inertial lag properties of the limbs, the athlete may also be able to take advantage of the myotatic reflex property of muscle within the triceps (Vander, 1994). This "stretch reflex" is a monosynaptic reflex initiated by stretching the muscle spindles and resulting in the immediate development of tension within the muscle. The actual muscle spindles are sensory receptors interspersed throughout the muscles and are oriented parallel to the fibers. These spindles respond both to the amount of muscle lengthening as well as the rate of muscle lengthening of the muscle (Nordin & Frankel, 2001). This means a quick stretch or rubber hammer tapping a muscle or tendon may elicit the stretch reflex.

It is common in throwing skills to see the elongation of a muscle prior to that same muscle contracting; and seems evident from the previous discussion that this stretch before shortening results in a greater contraction than if the muscle had not been stretched. In the current study, this is visible as the maximal bilateral elbow flexion prior to elbow extension being beneficial to increasing release velocity. A similar stretch before action occurs at the shoulder medial rotators and shoulder horizontal adductors during the pitching skill in baseball, or the lower body hip flexors and knee extensors in a maximal effort sagittal plane kicking skill. A bowler will lengthen the anterior deltoid, the clavicular head of pectoralis major, the long head of biceps brachii and coracobrachialis with shoulder hyperextension in the backswing to maximize the potential force from the shoulder flexors during force production.

An interesting finding with possible application to the long snap is the possibility of activity-dependent potentiation (MacIntosh et al, 2006). It was found that after tetanus of a muscle has been stopped, the given response to a single shock within a few minutes will be enlarged. The same phenomenon was demonstrated following a voluntary contraction and has been termed postactivation potentiation when referring to voluntary contractions and posttetanic potentiation when referring to electrically elicited contractions.

Professional athletes could apply this by receiving an electrically elicited tetanus in their elbow extensors prior to each long snap. Or perhaps a less invasive experiment would be to have long snappers voluntarily perform isometric and/or eccentric shoulder and elbow extensor loading prior to snapping the football to measure the effect on release velocity.

Left Elbow Extension Range of Motion

Since the football is released with nearly fully extended elbows (Figure 5.10B), and the university group was assuming a higher degree of maximum left elbow flexion, it was not surprising that they also showed a significantly greater range of motion at the left elbow when compared to the high school group. Mean left elbow extension range of motion in the high school group was 47°, while the university group demonstrated a mean range of motion of 68° at the left elbow.

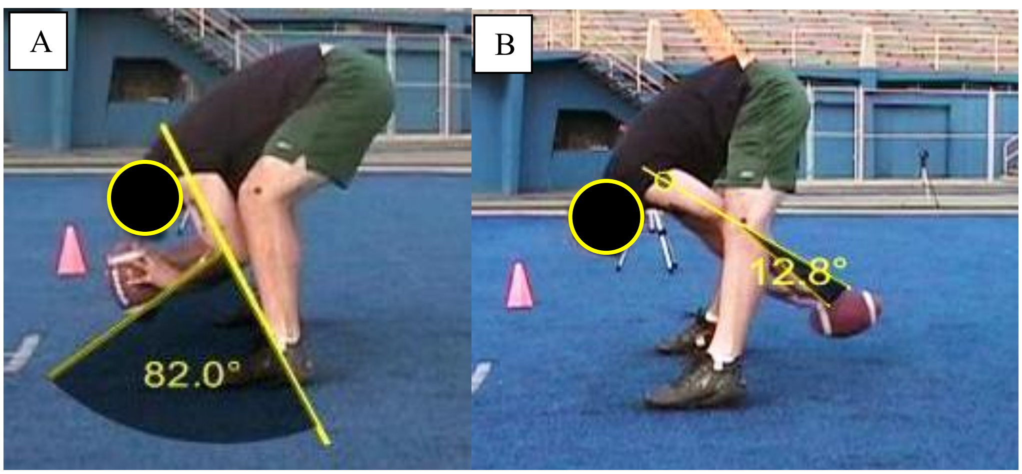


Figure 5.10: Maximum elbow flexion (A) and elbow flexion at release (B) in UNI subject.

This increase in range of motion is mainly the result of the university group's greater angle of maximum left elbow flexion previously discussed. An increase in the range of motion should increase release velocity due to the increased time over which the athlete can apply force to the football. This discussion is based on the force remaining constant or increasing over a larger range of motion. If the force decreases over a larger range of motion, it may negate the gains made from the longer time. Providing the range of motion is such that athlete can maintain force, this increase in time will increase the total impulse. This will alter the momentum of the football; where the impulse (F•t) is equal to the change of momentum ($m \cdot v_{final} - m \cdot v_{initial}$) that it is able to produce (Hay, 1993), also known as the impulse-momentum relationship.

Left Elbow Extension Velocity

With similar elbow extension times as the high school group, the university group was able to achieve significantly greater left elbow extension velocities than the HS subjects. Mean left elbow extension velocity in the high school subjects was 498°/sec, significantly lower than the 752°/sec demonstrated by the university group. Referring again to the formula $V=r \cdot \omega$ for converting angular velocity to linear velocity, a greater angular velocity (ω) will result in a proportional increase in linear velocity (V) of that limb (lever). Therefore, even if the athletes are of similar size and arm length (r), the increased angular velocity of the limb will result in greater release velocity of the football.

The elbow extension velocities demonstrated by the long snappers in the study were lower than other maximal throwing skills that have been analyzed. Baseball pitchers throwing fastballs are demonstrating the highest numbers with maximum elbow extension velocities regularly reaching 2400°/sec (Fleisig et al, 1996). These are maximum velocity values and not average velocity. The 752°/sec average velocity demonstrated by the UNI group would likely not measure much higher as a maximal reading due to the short time frame in the long snap, but it would be higher. Fleisig & Escamilla (1996) suggest elbow extension reaches maximum velocity 91% through the range of motion of the movement. Javelin throwers reached maximal values of over 2000°/sec (Komi & Mero, 1985). Elbow extension velocity in university football quarterbacks was measured at 1518°/sec (Rash &

Shapiro, 1995) and 1607°/sec (Toffan, 2009). Elliott & Armour (1988) reported elbow extension values of 1014°/sec in water polo players. Long snappers are unable to utilize the hip and shoulder rotation achievable in these other skills, which would allow more joint forces to summate prior to the lower arm. It is for that reason that the present researcher is assured of the contribution of elbow extension in the long snap as a major force producer.

Elbow extension velocity in the long snap appears to be at a low enough threshold that it may be able to be increased by contraction. It is unlikely in a skill like pitching that the elbow extensors can shorten fast enough to generate 2400°/sec velocities at the elbow (Fleisig & Escamilla, 1996). With a one handed delivery, the lower arm may be along for the ride in a sequence of joint movements that sum joint forces to the throwing hand through the forearm. Fleisig and Escamilla (1996) reported that a pitcher with a paralyzed triceps (through differential nerve block) was still able to throw a ball over 80% of pre-paralyzation velocity. This suggests a largely diminished role of the elbow extensors in pitching despite the extreme angular velocity of elbow extension.

It is likely that the UNI long snappers are stronger and more physically developed than the high school athletes. This may explain their ability to achieve a notably higher lower arm angular velocity at the elbow, produced by their ability to exert a greater torque about the elbow by the triceps brachii muscle group. This greater torque is supported by the angular version of the impulse-momentum relationship ($T \bullet t = I \bullet \omega_{final} - I \bullet \omega_{initial}$), stating the rate of change of angular momentum of a body is proportional to the torque causing it and the change takes place in the direction in which the torque acts (Hay, 1993). Since the moment of inertia (I) of the football remains constant through the skill and both groups had comparable elbow extension times, the difference in angular velocity can be attributed to a greater torque (T), which is the essentially the angular application of muscle force. Stronger muscles due to maturity or training mean the athlete can maintain the same release time, with a much greater angular velocity (ω) of the lower arms which will translate to a greater release velocity of the ball as demonstrated by the university group in the study.

Correlation Analysis

After an independent correlation analysis was conducted for both groups in force production, several variables in the force production phase were shown to be highly correlated with release velocity. In the high school subjects, right and left forearm pronation range of motion were shown to be significant. In the university subjects, maximum left elbow flexion angle prior to extension, maximum right elbow flexion angle prior to extension, as well as right elbow extension range of motion during force production were shown to be significantly correlated.

Within the high school group, the range of forearm pronation (in both arms) proved to be significantly correlated with release velocity. In fact, the correlation coefficients of the right ($r=-0.766$) and left ($r=-0.763$) forearms showed highly negative relationships to the football's velocity at critical instant. This means that the more pronation demonstrated, the less the release velocity in the high school subjects.

This is difficult to compare to other throwing motions like the quarterback pass or baseball pitch because the two handed bent over snap delivery is limited in range of motion when compared to the upright one handed delivery. Long snappers in the study moved through 10° (HS) and 8° (UNI) of right forearm pronation range of motion prior to releasing the football. When throwing a fastball, a pitchers' range of motion of pronation is nearly maximal to ensure the hand is facing forward at release (or a line made between the radial and ulnar styloid processes is perpendicular to the direction of the throw). The pronation range of motion from backswing to critical instant has been reported at 87° (Brown, Niehues, Harrah, Yavorsky, & Hirshman, 1988) in major league pitchers. Prentice (2009) reports the entire range of pronation motion as approximately 90° which would support the statement that baseball pitchers are going through the full range, and the evidence that long snappers travel through the majority of this range after force production has ended. The lack of trunk and hip rotation in particular is evidently lacking in the long snap, as well as the inability to laterally rotate the shoulders and supinate the forearms which contributes to a decreased pronation range of motion prior to release.

A negative correlation of bilateral pronation to release velocity in the long snap is an interesting discovery which is likely (at least partially) an indirect result of the high school subjects releasing the ball too high. Although it was not a significant difference, the high school subjects demonstrated a mean pronation range of motion of approximately 10° from arm/leg contact to critical instant, while the university group showed pronation range of motion means of approximately 7.5° over a similar time frame. This is only a few degrees difference, but represents a relatively large percentage difference. As reported in the results, the high school subjects released the football significantly higher than the university subjects. A higher release point means the high school snappers hold on to the football slightly longer, meaning they pronate bilaterally slightly more before the ball is released. A coaching article (Grindle, 1999) suggests the snapper should "flip" the hands over during delivery to have the thumbs pointed upward after release (Figure 5.11). The "flip" is in reference to the forearm pronation, wrist flexion, and slight wrist adduction that occur through release of the ball. This "flipping" motion represents the end of the follow through phase and occurs in the terminal range of forearm pronation, causing the thumbs to point upward. This researcher does not believe that it would be beneficial to ask young snappers to reduce this motion, but instead to attempt to keep their release height down which would result in less pronation at release. Fracas & Marino (1989) suggest the long snapper should "reach" back towards the punter while delivering the football which may stop the hands from moving too far vertically prior to release. This "reaching back" position (Figure 5.11) may help to keep release height down, and a lower release height would likely reduce the degree of bilateral forearm pronation at release.

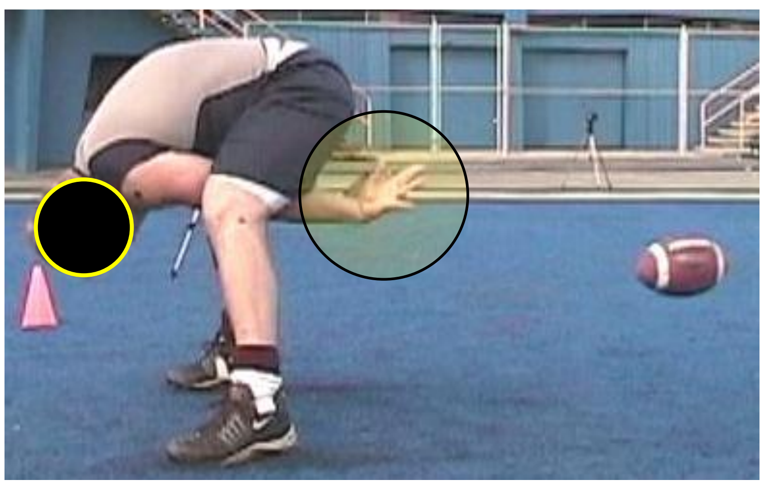


Figure 5.11: Image showing the thumbs are pointed upward due to maximal pronation shortly after the release of the football during the follow through of the long snap.

Within the university group, maximum right and left elbow flexion angles (prior to extension) in the force production phase had significant relationships to release velocity. The high positive correlation between maximum elbow flexion angles (Figure 5.10A) was slightly higher on the left side (r=+0.702) than on the right (r=+0.633), though both were remarkable. This relationship means that with higher degrees of maximum elbow flexion, higher release velocities were attained by the university subjects.

The UNI snappers moved from 85° of elbow flexion through to 15° at critical instant. Fleisig et al (1996) found that baseball pitchers had similar ranges of motion from 85° of maximum flexion to 20° of flexion at release, and quarterbacks moved from 113° to 36° of elbow flexion through delivery. The elite pitchers in that particular study demonstrated as much as 100° of maximum elbow flexion. Sakurai et al (1993) reported maximum elbow flexion as high as 114°, but it is noted that those pitches were released with 35° of elbow flexion; therefore the range of motion is similar to the previous example. When discussing elbow flexion in the long snap, this researcher suggests the only limit to elbow flexion should be if the ball contacts the player's helmet. This would likely occur with flexion angles greater than 120° due to the bilateral nature of the throw.

Long snappers initially flex the elbows during the first part of force production prior to extending them, and higher degrees of flexion mean a greater range of motion during extension. Increased range of motion indirectly affects release velocity by first increasing the total time for angular impulse (T•t) on the ulna about the elbow. If the force can be maintained (the athlete is strong enough) to apply the same torque for the duration of the skill, then a longer time of application will increase the total angular impulse. A torque applied over time can then change the angular momentum (H) of a body or object based on the impulse-momentum relationship. This becomes visible as a change in the angular velocity (ω) of the extending elbow since there is little change to the moment of inertia of the swinging limb.

If the angular velocity of the elbow extension (ω) increases and the length of the limb (r) remains constant, then based on the formula V=r•ω, a proportional change will be seen in the linear velocity (V) of the hands with an increase in 'r' or 'ω'. The hands will then impart this greater linear velocity to the football, which is visible as an increase in release velocity. This can usually be done by increasing the range of motion of a joint, as demonstrated by the significant correlation between maximum right and left elbow flexion angles (prior to extension) and release velocity of the long snap. This is not always the case in throwing skills, particularly skills that have the elbow extending faster than the elbow extensors can contract. Javelin deliveries for example move the elbow from a position of 100° elbow flexion to 54° at release (Komi & Mero, 1985), which is a smaller range of the motion than the long snap, yet at a much higher angular velocity (2000°/ sec). This researcher was unable to locate a quantification of the angular velocity at the elbow which exceeds contraction velocity. It seems that a skill like the long snap may experience a plateau in release velocity once that threshold is achieved.

This previous discussion helps to explain why right elbow extension range of motion appears as a highly correlated variable to release velocity (r=+0.670) in the university group long snappers. What is perhaps more interesting here is not why right elbow extension range of motion is highly correlated to release velocity, but why left elbow extension range of motion is not; considering that both right and left maximum flexion angles prior to extension appear as significantly correlated values in the university group to release velocity. The university group also showed significantly higher measures in left elbow extension range of motion and left elbow extension velocity means (*t*-tests) when compared to the high school group. Maximum left elbow flexion angle as well as left elbow extension range of motion also appeared as predictors of release velocity in the regression models.

This researcher believes the exclusion of left elbow extension range of motion as a significantly correlated variable to release velocity in the university long snappers is due to the design of the study. The low sample size study design (N=20) analyzes dozens of kinematic variables and runs a higher risk of committing a type II error, or false negative. A type II error occurs when the effect (for example the correlation of left elbow extension range of motion to long snap release velocity in the force production phase) is present in the population, but the sample taken does not provide enough evidence to reject the null hypothesis (Hassard, 1991). It has become apparent to the researcher that when looking at all of the study results, left elbow movements play a major role in successful high velocity long snaps. The exclusion of maximum left elbow flexion from the list of significant correlation variables is likely a result of small sample size.

Predictors of Release Velocity

In the HS only model, no variables were selected from the force production phase as possible predictors to release velocity. In the UNI only model, maximum left elbow flexion (in force production prior to elbow extension) was selected to predict release velocity. In the regression model for HS and UNI long snappers combined, left elbow extension range of motion was selected as a predictor of release velocity. Inclusion of left elbow extension range of motion demonstrates further justification for this variable being identified as a key variable in analyzing long snaps or predicting their velocity.

Within the UNI subjects, maximum left elbow flexion was returned as a possible predictor of release velocity. This variable had a coefficient of +0.026 in the UNI regression model. Therefore, for every ten degree increase of maximum left elbow flexion in the force production phase, there would be a 0.26 m/s increase in long snap release velocity. This coefficient suggests that increased maximum left elbow flexion may increase release velocity in high school snappers. This researcher supports the inclusion of maximum elbow flexion angle in the model based on previous discussion. It appears to be a valid predictor of release velocity and is relatively easy to observe. Even without advanced digital video analysis, coaches could estimate elbow flexion angles to monitor the contribution to their long snapper's release velocity.

The HS and UNI combined regression model also returned a familiar variable, left elbow extension range of motion, as a possible predictor of release velocity in all long snappers from the study. With a coefficient of +0.022 in the model, it suggests that with a nine degree increase in left elbow extension ROM, there would 0.2 m/s increase in release velocity. This relationship is demonstrated by comparing a trial showing left elbow extension range of motion in a subject who achieved a lower release velocity (12.11 m/s) to the left elbow extension range of motion in the trial of a subject who achieved a higher release velocity (16.18 m/s) (Figures 5.12 & 5.13). There is a lack of left elbow range of motion (20°) in the 12 m/s trial when compared to the left elbow range of motion (70°) in the 16 m/s trial. The range of motion at the elbow appears to be a crucial development within the skill that helps to separate high and low release velocities in HS and UNI long snappers.

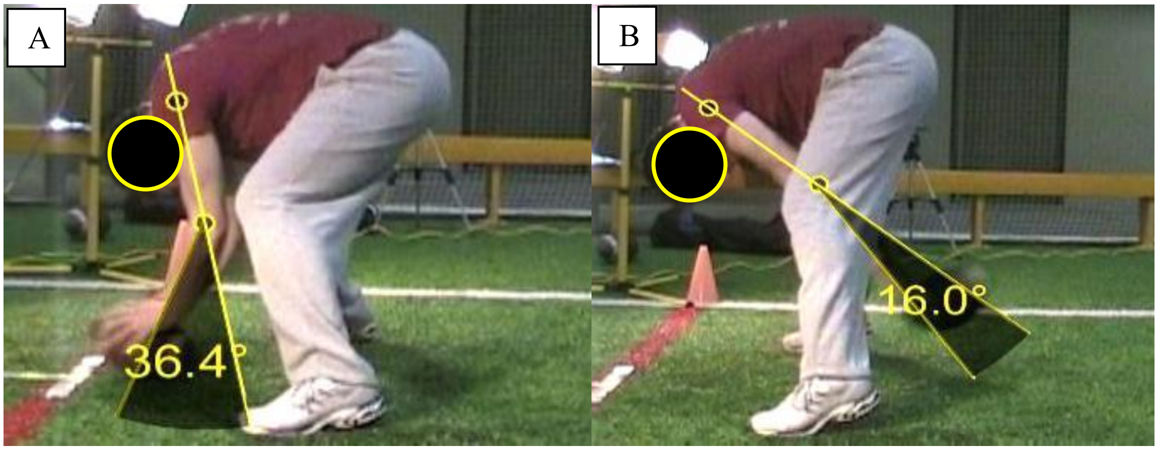


Figure 5.12: Illustration of a low value of left elbow extension ROM (20.4°) by showing left elbow maximum flexion (A) and critical instant (B) in a low velocity trial (12.11 m/s).

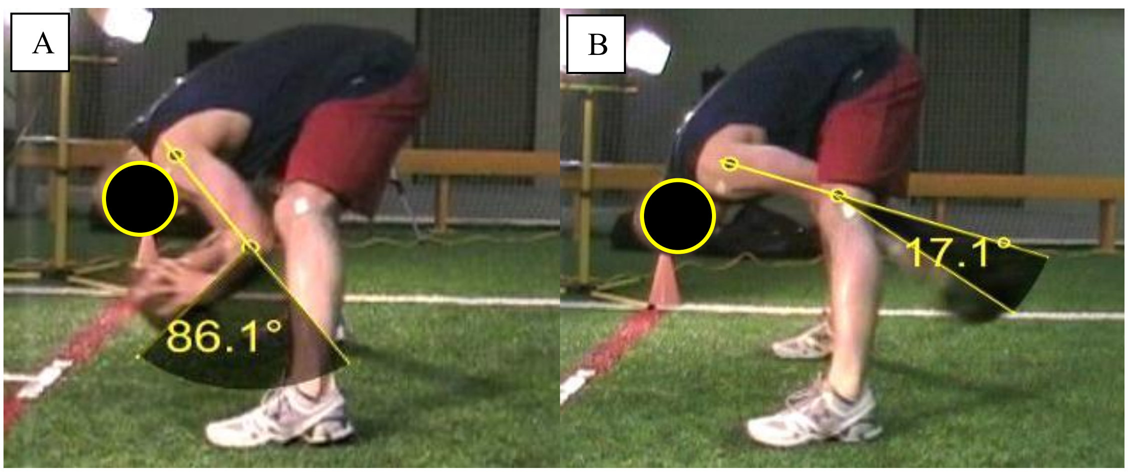


Figure 5.13: Illustration of a high value of left elbow extension ROM (69.0°) by showing left elbow maximum flexion (A) and critical instant (B) in a high velocity trial (16.18 m/s).

Predictors of TST

In the TST regression model for HS and UNI long snappers combined, just as in the previous regression model, left elbow extension ROM was determined to be a predictor of total snap time. Once again, range of motion at the left elbow during force production is raised as an important variable in analyzing long snap performance. Whether predicting release velocity or TST, an increase in the athlete's left elbow extension ROM must be regarded as a key coaching point when improving the unique skill of the long snap.

It was interesting to note that right shoulder medial rotation range of motion was also determined to be a predictor of total snap time in the TST regression analysis. With a positive coefficient (+0.006) in the model, it is suggested that an increase in medial rotation at the right shoulder will increase total snap time. This is likely explained by the effect that further medial rotation would have on release time, as well as total flight time of the ball (the two variables that make up TST). If the athlete goes through more medial rotation range of motion, he may increase his release time, which would have a negative effect on TST. If the release time is increased, then it is likely that the ball is also being released at a higher height and higher release angle (Figure 5.21). This suggests the total flight time of the football will be increased by the higher trajectory, thereby also increasing TST. Although shoulder medial rotation likely contributes to the angular velocity of the ball, it does not appear that a decrease in angular velocity will reduce TST when observing all subjects. It appears that linear velocity is more important than angular velocity when improving long snap performance.

Critical Instant

The critical instant is the moment the football leaves the hand and the athlete is no longer able to impart force to the projectile (Figure 5.14). This instant represents the end of the force production phase and the beginning of the follow through. The airborne phase which has been discussed in the study also falls into this phase since it may occur just prior to, during, or just after critical instant. Many critical instant variables were found to be significant; not only to identify differences between the groups, but to identify variables that show a high correlation to release velocity, as well as being possible predictors of higher release velocities in developing long snappers.

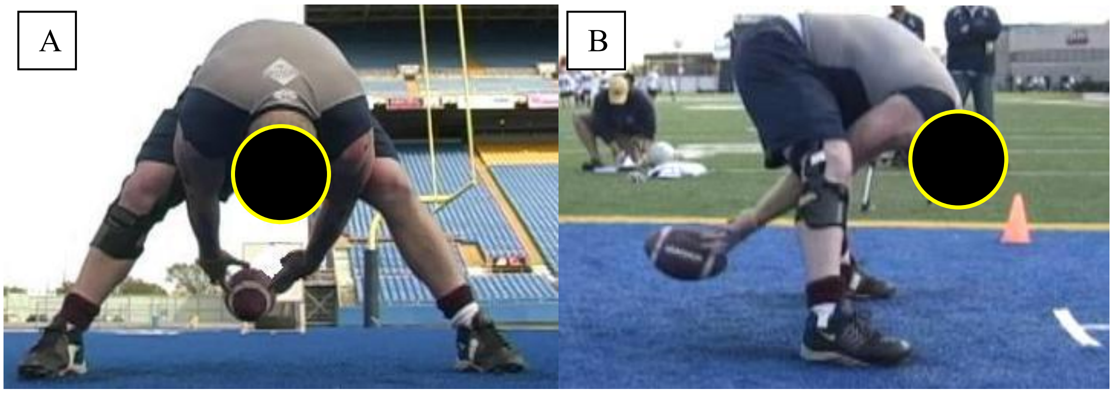


Figure 5.14: Front view (A) and sagittal right view (B) of critical instant of the long snap.

Heel Distance Covered

Analysis has revealed that successful long snappers seem to move backward toward the punter (Figure 5.15) throughout the snapping motion (Zauner, 1985). Blegen et al (2005) identified this movement as the "flight" phase of the snap, and found that the backward and upward movements of more skilled snappers were significantly greater than less skilled athletes. Blegen et al (2005) reported the change in the position of the centre of mass in the anterior posterior direction (ΔCM_{ap}) as 0.27 m for the university group and 0.14 m for the high school.

The current study did not look at the vertical movement of the athlete, only the backward or horizontal movement as measured by distance covered by the heels and found similar values to those reported by Blegen et al (2005). Statistical *t*-tests revealed a significantly higher mean distance of 0.30 m for the average distance covered by both heels in the UNI athletes, when compared to the HS mean distance of 0.16 m. This distance was found by measuring the distance of the right and left heel displacements, and solving for the average. Right heel distance, left heel distance and mean distance covered were all significantly greater in the UNI group (Figure 5.15) when compared to HS long snappers (Figure 5.16).

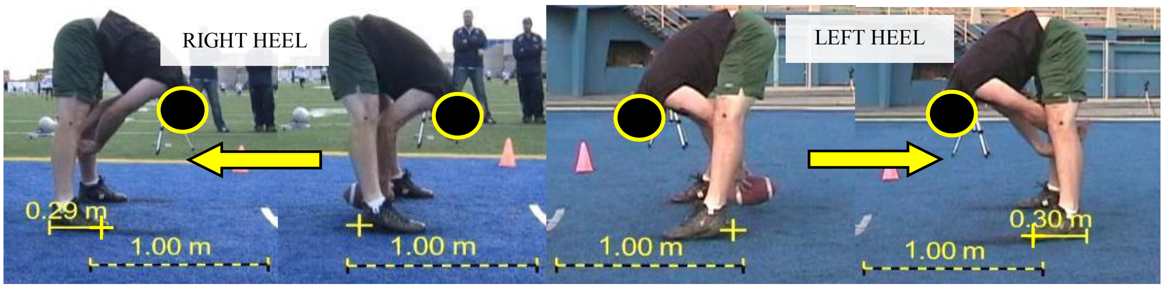


Figure 5.15: Example of UNI subject showing higher right (0.29m) and left (0.30m) backward heel distances covered in airborne phase which begins at or near critical instant.

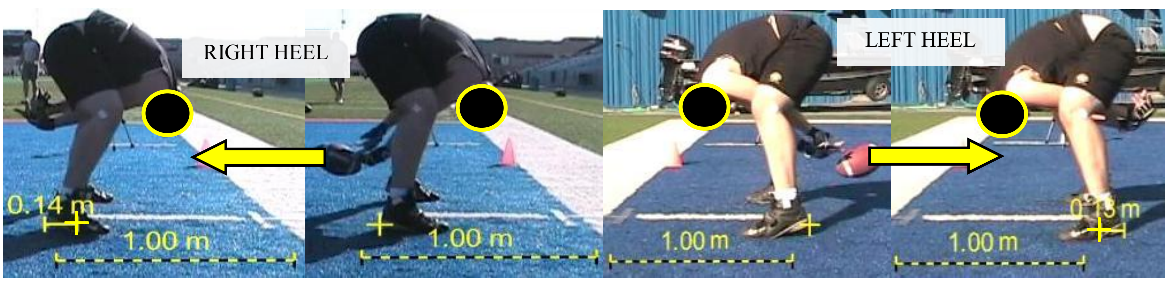


Figure 5.16: Example of HS subject showing lower right (0.14m) and left (0.13m) backward heel distances covered in airborne phase which begins at or near critical instant.

These numbers support the discussion that more skilled athletes move backward further during the delivery of the long snap. If the movement backward is initiated prior to the critical instant (as seen in Figure 5.15), then the argument can be made that it may add to the release velocity in three ways. The first is by lengthening the distance through which force is applied to the ball, thereby taking advantage of the impulse-momentum relationship. If force is applied over a greater distance, then it is likely that over a greater time, a greater change of the football's momentum can be achieved. If the backward movement is initiated before release, the athlete may also add his body's backward velocity to the velocity of the football (Blegen et al, 2005) which is a transfer of momentum that will also increase ultimate release velocity. The long snapper's accuracy may also improve from this backward movement coinciding with delivery by flattening the base of the arc made by the swinging arms, and allowing the ball to be pointed at the desired target for a longer period of time (Figure 5.17).

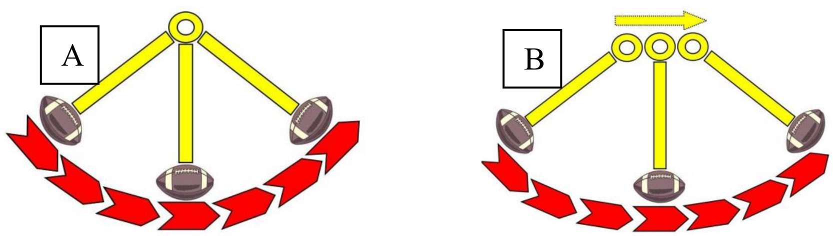


Figure 5.17: The "normal" parabolic arc of the football if the body remains stationary (A) and the "flattened" parabolic arc when the athlete moves backwards during delivery (B).

In some cases the athlete has not yet started moving backward when releasing the football (as seen in Figure 5.16). This would make the contribution of the airborne phase to force production impossible, since force can no longer be imparted to the football once it has been released. Within the study data, it appeared that the subjects who initiated the airborne phase at or after critical instant traveled lesser distances in the backward direction. This would suggest a correlation of distance traveled to release velocity, although this was not entirely supported when the correlation analysis was conducted, however it did appear as a trend in the high school group.

Total Snap Time (TST)

The time it takes the football to reach the punter when measured from the long snapper's first movement is how total snap time (TST) is calculated. TST can be further broken down into release time (RT) or the total time of force production, and the total flight time (TFT) of the football or the total time in the air before reaching the punter. When comparing the RT group means, they were not significant although were interestingly slightly greater in the UNI group (215 milliseconds) than in the HS group (206 ms). Although a small difference, this further supports the value of incorporating the impulse-momentum relationship ($F \cdot t = \Delta M$) to describe the increase in release velocity. The increased time of force application demonstrated by the UNI subjects allows them more time to impart force to the football, thereby increasing the change in momentum transferred to the football which is measured as an increase in release velocity. This discussion assumes that the force of the elbow extensors remains constant or increases in the UNI athletes, for if it does not, then the increase in range of motion may be detrimental to the impulse-momentum relationship.

Although the RT of the football during force production was not shown to differ statistically between the groups, the TFT and TST both proved to be significantly slower in the HS group (1.04 and 1.25 s) when compared to the UNI group (0.87 and 1.09 s). Many coaches will focus mainly on TST, since this is the variable that can be easily measured with a stopwatch. Findings of the study suggest that TST will be strongly and negatively correlated to release velocity, which is understandable. It is for this reason that the researcher completed the fourth regression model using TST as the dependent variable instead of release velocity. Data analysis may be limited by predicting release velocity with TST since these two variables are so closely related. By removing release velocity from the fourth regression analysis to predict TST, the researcher was able to observe which kinematic variables would serve as predictors of performance. Since TST would dominate the release velocity regression model, and vice versa, this was an important step in understanding the movements that contribute to successful snaps.

Although differences in TST may be attributed to various possible factors, the bottom line is that a faster snap time is beneficial provided it coincides with an accurately delivered football. It is for this reason that many long snappers are rated solely on their TST. Zauner (1985) rates professional long snapper times as follows: Excellent–0.6 to 0.7 seconds, Decent–0.8 s, and Poor times as 0.9–1.0 s. Blegen et al (2005) measured TST over a slightly lesser distance (11.95 m) than used in this study (12.8 m) and found the high school group had a mean time of 1.25 s, while the university group was significantly faster at 0.85 s. These times were comparable to those found by this researcher (HS-1.25 seconds and UNI-1.09 seconds), albeit a slightly shorter distance (11.95 m) was used by Blegen et al (2005) than in the current study. When comparing these total snap times to Zauner's (1985) ranking system, UNI snappers compare to "Poor" professional long snap times, while HS snappers are three tenths of a second from the "Poor" rating and need to halve their snap times in order to compare to elite players.

A decreased TST allows more time for the punter to handle and kick the ball before the rushers arrive, more time for the long snapper to react to the defensive rushers and assist in the blocking scheme, and less time for the rushers to attempt to block the football before it is kicked. When comparing high school and university long snappers, this study demonstrated the UNI long snappers were able to achieve lower total snap times than HS long snappers. Besides their maturation and physical development, more experienced long snappers have the distinct advantage of more repetitions of practice. In closed skills like the long snap, execution is reliant on practicing the temporal sequencing of the skill. The long snapper must coordinate several body movements in the correct order, with the proper timing to maximize force production in a very limited time frame.

The results of the study also suggest it may be likely that different players are able to perform the skill successfully using different strategies. Temporal sequencing was not analyzed in the study, nor was the relative timing of key movements within the skill. There may be different methods to achieve the perfect snap depending on the athlete's height, limb length, strength, flexibility or maturity. This is important to note when analyzing or coaching the skill since the ultimate goal is a fast and accurate snap, which may be achieved using different movement strategies. With such a range in athlete characteristics, there is likely more than one way to pigskin the proverbial cat.

Release Height

High school long snappers in this study released the football from a greater height than university long snappers. The difference was significant with absolute mean release heights of 0.17 m (HS) and 0.13 m (UNI). The p-value of this difference was further reduced (made more significant) from 0.00052 to 0.00025 when the release height was reported as a percent of the athlete's standing height. Mean relative values were reported as 9.1% (HS) and 7.0% (UNI) standing height. It is evident that more skilled long snappers are able to keep the release height of the football lower than their lesser skilled counterparts (Figure 5.18). Although the difference in release angle was not significant, the HS snappers also released the football at a steeper angle (24°) when measured from the horizontal than the UNI group (19°) (Figure 5.19). The university subjects released the football from a lower height with a lesser angle of release, suggesting the UNI footballs are traveling at a greater release velocity. If the UNI footballs are moving faster, they will be able to take a more direct path to the punter (straight line). Henrici (1967) suggested this as a marker for better long snaps when suggesting that the release velocity of the long snap should vary only slightly from the average velocity of the football over its entire trajectory. This certainly held true in the current study with the higher velocity trials demonstrating lower release heights and lower release angles.

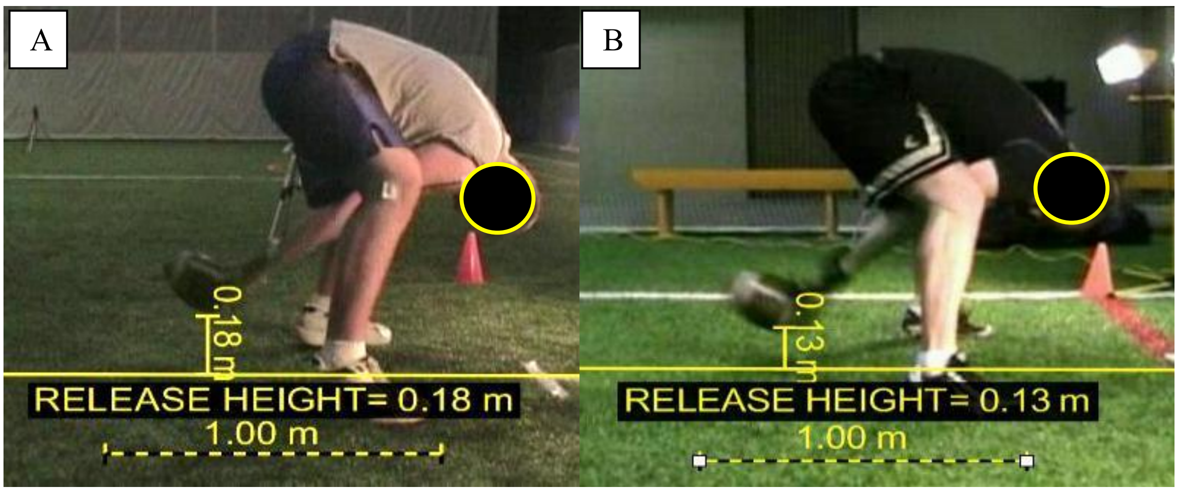


Figure 5.18: Example of a high school long snapper (A) and a university long snapper (B) at the moment of critical instant to measure release height. High school long snappers in the study demonstrated a significantly higher release height than university athletes.

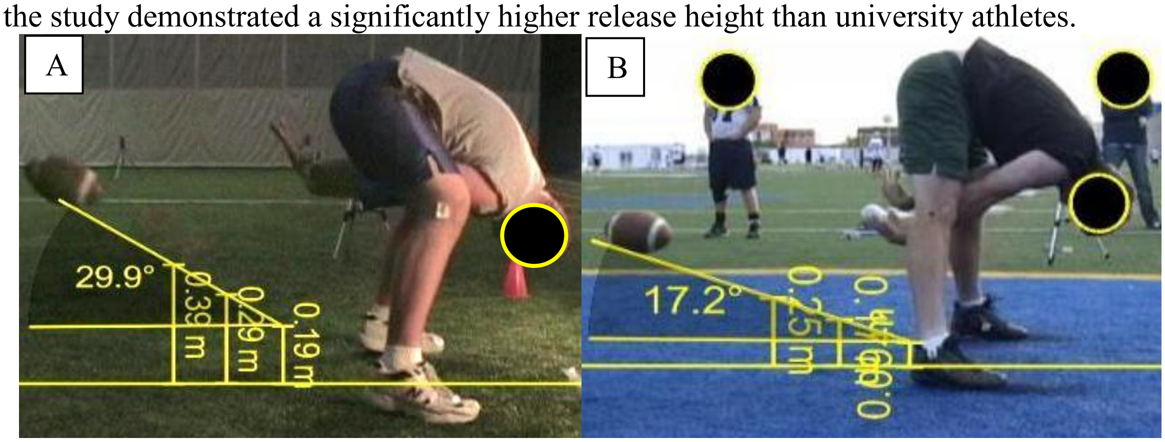


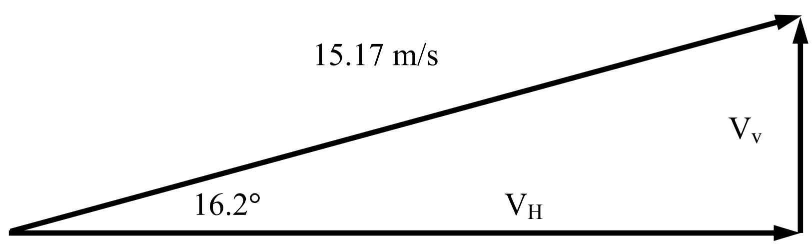
Figure 5.19: Illustration of a high school long snapper (A) and university long snapper (B) three frames after critical instant to measure release angle. The HS subjects in the study demonstrated a higher release angle than UNI athletes.

The high school athletes have adjusted their delivery to compensate for less velocity. If the football were released from a lower height, or at a lesser angle (from the horizontal), then it would not reach the punter's right hip (the desired target). The horizontal velocity component of the release velocity vector is not large enough due to strength and limb length deficiencies, therefore the vertical velocity component must be increased to give the football enough time in the air to reach its target. In order to release the football with more vertical velocity, the high school long snappers must throw the football more upward instead of backward. This adjustment is measured as an increase in vertical release height as well as an increase in release angle (degrees from the horizontal). The main advantage to altering the release height is to alter the position in the arm swing at which critical instant occurs.

Football Velocity

The study design called for the measure of release velocity as well as the average velocity of the football throughout its flight. The reason for average velocity inclusion is to verify that the football is demonstrating minimal vertical displacement during its path. If there is a notable difference between release velocity and average velocity; the football is likely to be traveling upward and downward, instead of only upward.

The release velocity vector of the football at its measured release angle can be broken down into a horizontal and vertical component. Figure 5.20 illustrates how to solve for the horizontal and vertical components of a football snapped at 16.2° with a release velocity of 15.17 m/s. If the horizontal component is maximized, and the vertical component is minimized, the ball will travel in the most direct line possible toward the punter. Since the ball is released from lower than it is received, it must travel upward during flight. The vertical velocity component of the release vector is important, since if the vertical velocity component is too low or too high, the resultant snap will likely be the same. What is also clear is that if the horizontal component of velocity is not large enough, an increase in the vertical component is necessary. This increase in vertical velocity will give the ball a high enough trajectory to remain in the air long enough to reach the punter.



Solve for horizontal velocity

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\therefore \cos 16.2 = \frac{\text{horizontal}}{15.18}$$

$$\therefore V_H = (\cos 16.2)(15.17)$$

$$\therefore V_H = 14.568 \text{ m/s}$$

Solve for vertical velocity

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\therefore \sin 16.2 = \frac{\text{vertical}}{15.17}$$

$$\therefore V_V = (\sin 16.2)(15.17)$$

$$\therefore V_V = 4.232 \text{ m/s}$$

Figure 5.20: Sample calculation for determining the horizontal and vertical velocity components of a release velocity vector.

The formula for average velocity (v=d/t) takes only the horizontal displacement (d=12.8m) of the football into account when calculating it, with any vertical displacement of the football presenting itself as a decrease in average velocity by increasing the total time (t) in the air. As Henrici suggests (1967), with an increase in skill level, we would expect to see the difference between release velocity and average velocity decrease.

This statement held true for the study, where significant differences were found between the groups for release velocity as well as average velocity. The UNI mean release velocity was significantly faster at 15.15 m/s when compared to the 13.21 m/s HS mean release velocity, proving the initial hypothesis of the study. As expected, the difference between the mean average velocities of the UNI (14.75 m/s) and HS (12.51 m/s) groups was also significant. This made the difference between the release and average velocities much smaller in the UNI group (0.40 m/s) than in the HS group (0.70 m/s), demonstrated as a football that nearly maintains release velocity throughout flight. This further supports Henrici's (1967) suggestion that "the ball coming back (flight towards the punter) with no change in velocity" is an elite marker of consistent long snaps.

Correlation Analysis

After comparing the critical instant variables of each group against the dependent variable, six variables were shown to have a significant relationship with the release velocity of the long snap. Within the high school group, there were three significant variables (total snap time, release height % SH, release angle of the football) as well as one nearly significant variable (distance covered by the feet in the airborne phase) which all warrant further discussion. Within the UNI group, there were also three variables (total snap time, average angular velocity of the ball in flight, release angle of the football) which were highly correlated to release velocity.

Total snap time (TST) had the highest correlation to release velocity ($r=-0.915$) in the study's HS group. This is not a surprising discovery that a decrease in TST would be seen in trials with a higher velocity. What is important to take from this finding is that the

HS group had remarkably slower long snaps, and increased total snap times, yet faster release times than the UNI group. The faster release time which is decreasing TST is largely offset by the increase in flight time (and TST) with a ball that receives a shorter impulse during the force production phase.

The release height of the football as % SH was significantly correlated (r=-0.848) to release velocity in the HS group. This negative relationship suggests that an increase in release velocity may allow for a decreased release height (Figure 5.18). The HS subjects also demonstrated a significant relationship (r=-0.825) between release angle (Figure 5.19) and release velocity, or that lower release angles are correlated with higher release velocity.

The release angle of the ball is directly related to the release height due to the semi-circular path of the lower arm about the elbow. The higher the position of the hands, the more vertical force they will impart to the football due to the rotation of the lower arm about the elbow in a circular motion (Figure 5.21A). This increase in vertical force imparted to the ball will result in a higher release height (white arrow) as well as a higher release angle (red arrow). Conversely, the lower the hands release the football, the closer they will be to the lowest point of the circular path where they are imparting more horizontal force (Figure 5.21B) in the backward direction and less vertical force than when the hands are higher at release. More horizontal force applied to the ball will result in a long snap with a decreased release height (white arrow) and a decreased release angle (red arrow). The study data strongly suggests that an increase in release velocity will be related to a decrease in these two variables (release height and release angle) when performing the long snap. By increasing release velocity and decreasing height and angle of release, it is likely that TST will also be improved.

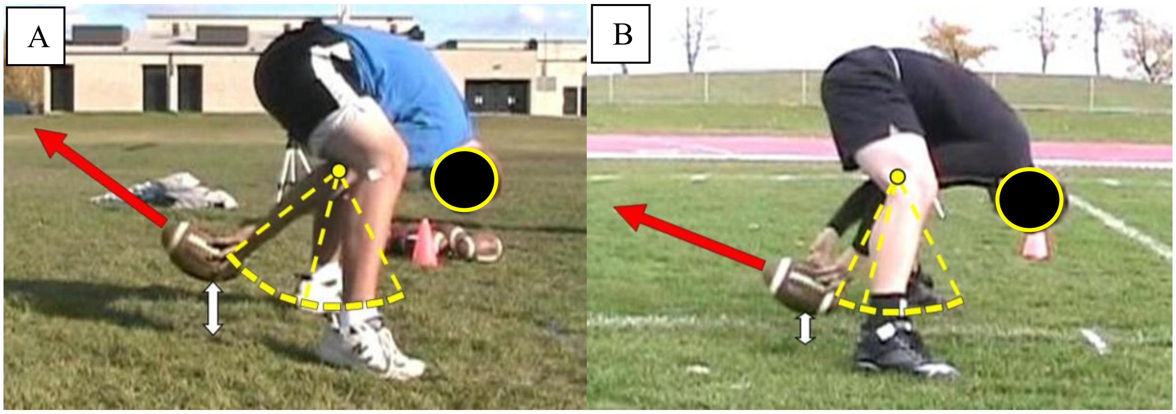


Figure 5.21: Illustration of the direct relationship between high (A) and low (B) release height of the football (shown with a white arrow) and the higher (A) or lower (B) release angle (red arrow) due to the semi-circular path of the hands during elbow extension.

Zauner (1985) described this more horizontal release by stating that a good snap has the centre releasing the ball when the football is nearly parallel to the ground. The ball is almost parallel to the ground when at the bottom of its semi-circular path. Blegen et al (2005) found that this position of the football at release was also facilitated in their study by the UNI snappers keeping their trunk more horizontal at release than the HS group. That difference in trunk position at critical instant was not replicated in this study, even with the UNI snappers demonstrating significantly lower release heights and angles. The UNI group in this study did demonstrate slightly higher shoulder flexion angles at critical instant (though the difference was not significant). This adjustment in shoulder position would assist the athlete in releasing the ball closer to the ground while still allowing for nearly complete elbow extension.

Although it did not prove to be a significantly correlated variable, the relationship between the distance covered (average of both feet) during the airborne phase was nearing significance (r=+.617) when compared to release velocity in the HS group. Movement backwards towards the punter during the long snap may provide a benefit to higher release velocity by adding the momentum of the athlete to the momentum of the football. The backward movement may also improve accuracy when synchronized with the critical instant by increasing the amount of time the ball is on the flattened portion of the arc. This will keep the ball pointed at the desired target longer, contributing to accuracy.

Blegen et al (2005) found similar results which suggested that experienced long snappers whose release velocities were greater, were found to slide a greater distance towards the target during the snap. An instantly applicable benefit of this variable is that it is easily observable with the naked eye, providing coaches with a quick and somewhat accurate possible indicator of long snap success.

When analyzing the UNI subjects, total snap time (TST) was also the most highly correlated variable to release velocity (r=-0.908). This is another easily observable variable which can be measured with as little as a stopwatch, and is a definite inversely proportional indicator of release velocity. Release angle was also returned as a strongly correlated variable to release velocity (r=-0.720) in the UNI subjects, as it was in the HS group.

The ideal long snap trajectory is one in which the ball travels along an imaginary straight line from release point to the desired target, rising the entire time (Henrici, 1967). It is difficult to snap the ball with enough velocity for this to happen, which is why the release angle decreases in both groups when the release velocity is higher. It can be theorized that this relationship would not continue to occur once the release angle matches the angle by this perfectly delivered football along the imaginary straight line (to the horizontal) from release point to punter (Figure 5.22). Once the athlete is skilled enough to match these angles, the release velocity could continue to increase without further change in release angle.

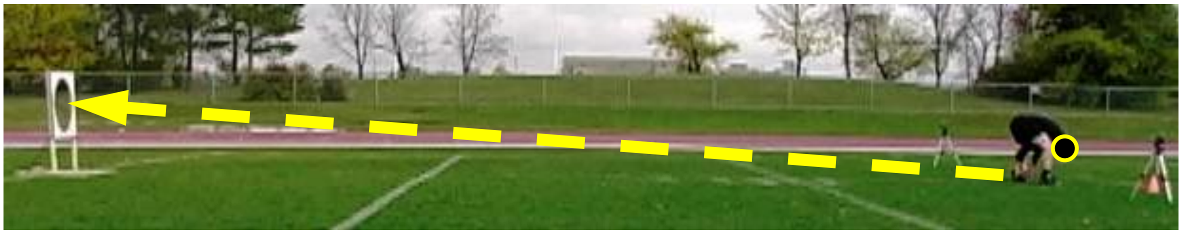


Figure 5.22: Illustration of the ideal long snap trajectory as a straight line which would cause release velocity and average velocity over flight to be nearly identical.

This would represent a highly elite level of long snap performance, and was not occurring in this study's subjects. That is why release angle had a high negative correlation to release velocity for both groups. Figure 5.23 shows the trajectory of a low velocity trial with much more vertical movement during flight and Figure 5.24 demonstrates the more direct trajectory of a high velocity trial.

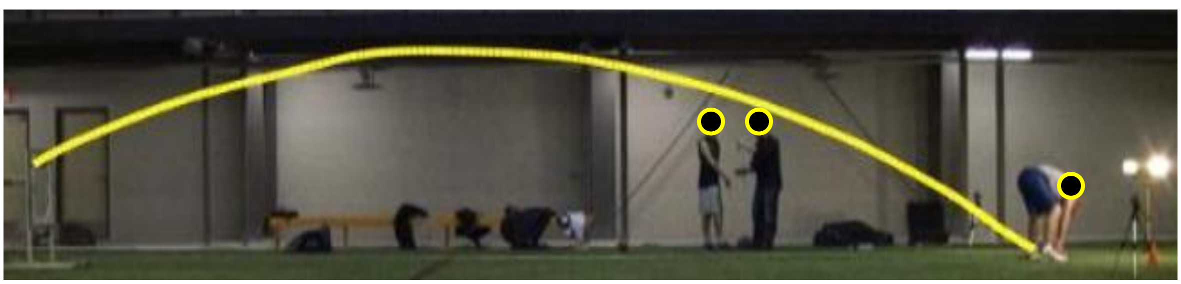


Figure 5.23: Illustration of the flight path of a low velocity long snap trial (12 m/s).

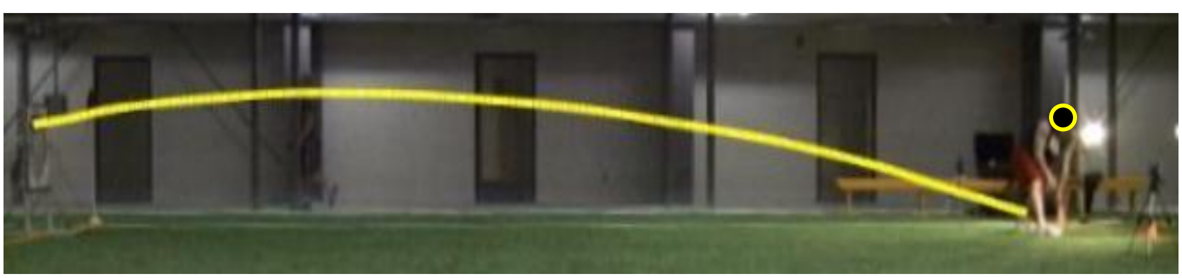


Figure 5.24: Illustration of the flight path of a high velocity long snap trial (16 m/s).

A final variable which was selected from the correlation analysis within the UNI group was average angular velocity of the football. It was found that angular velocity had a significant positive correlation (r=+0.722) to release velocity. This means that the UNI athletes who delivered a faster spinning (spiraling) ball tended to have higher release velocities. Although the same positive correlation was present in the HS group, the regression factor was only +0.524 and was not found to be significant.

The wrists flex and the forearms pronate to rotate the fingers outward (the fingers may also be flexing as torque is applied to the ball) to produce a tight spiral (Fracas and Marino, 1989). A "tight" spiral is best described as a ball that is spinning perfectly about its longitudinal axis and is seen as a ball that has little or no wobble in flight. By holding a football on its side, the thrower can impart considerable spin to the football about the long axis (Brancazio, 1985) which may help maintain the nose-first orientation of a well thrown football. A good spiral provides stability to the ball in the air producing a longer pass (Yessis, 1984), or in the long snap, may produce higher velocity over the set distance. A faster spinning football with a "tighter" spiral will also be less affected by external forces such as wind. A wobbling football presents more surface area to the oncoming fluid (the air), which would increase the drag forces acting on the ball and decrease linear velocity. Brancazio (1985) reported the variance of cross-sectional area between 0.02 and 0.04 m^2, depending whether it is spiraling nose first, or tumbling end over end. The total drag force on a football is proportional to the cross-sectional area that the ball presents to the air, the density of the air, and the square of its speed. Gay (2004) theorized that a spiraling football could retain as much as 59% of its kinetic energy through flight, which would be visible as a retention of velocity since KE(Kinetic Energy)=$\frac{1}{2}mv^2$.

Predictors of Release Velocity

In the HS only multiple regression model, total snap time (TST) was selected from the critical instant as a possible predictor to release velocity. In the UNI only model, three variables from this phase were included. Total snap time, left shoulder flexion angle, and relative release height of the ball were selected as possible predictors of release velocity in UNI subjects. In the regression model for HS and UNI long snappers combined, TST was the only variable selected from this phase as a predictor of release velocity.

Total time from first movement of the long snapper to the football reaching its desired target was the most powerful predictor of long snapping release velocity in this study's comparison of skilled long snappers. Within each of the three stepwise regression models (HS, UNI, HS+UNI), TST alone had r-squared values of 0.838, 0.849, and 0.898 (if it were the only variable being considered). This means that accurate TST measures may be able to explain 84 to 90% of the variation in the release velocity (dependent variable) of the football in the long snap. This converts to accurately predicting release velocity in HS or UNI level long snappers (within ~1m/s) simply by timing the movement. Zauner's (1985) category ranking scale for long snap performance based on TST is an effective and inexpensive example of using this variable as a lone predictor of fast snaps. A possible consideration for the rating system would be to include known skill levels within the ratings. For example, a simple TST chart that could provide ranges (1.3-1.5 seconds for example) with selective qualitative comments for known skill levels; such as BANTAM-Excellent, HS-Very good, UNI-Needs improvement, PRO-Too slow).

The UNI only regression model also identified left shoulder flexion angle and release height (as %SH) as critical instant variables that may be possible predictors to release velocity. Both of these variables have negative coefficients in the model which means that by decreasing either of those variables, an increase in release velocity may be predictable.

The left shoulder flexion variable may be able to improve the regression model, but it carries a small coefficient of -0.004. This means that 100° differences in left shoulder flexion angle at critical instant may be able to predict a change of 0.5 m/s in release velocity. On its own, that is not entirely useful, but by combining the variable with TST in the model, it explains nearly 3% more of the variation in release velocity. This supports the inclusion of this variable in the model, but reminds us of the risk of removing one variable from the context of the entire regression equation. What it means is that a lower left shoulder flexion angle at release may be a marker of higher velocity in UNI long snappers. Depending on the trunk flexion/hip flexion position of the athlete, a decreased left shoulder flexion angle would put the athlete in the position of "reaching back towards the punter" as described by Fracas and Marino (1989). This was verified in the video footage by comparing the left shoulder flexion angle at critical instant in two UNI long snappers with high and low release velocities to see if the lower left shoulder flexion angle was present in the subject with the higher velocity (Figure 5.25).

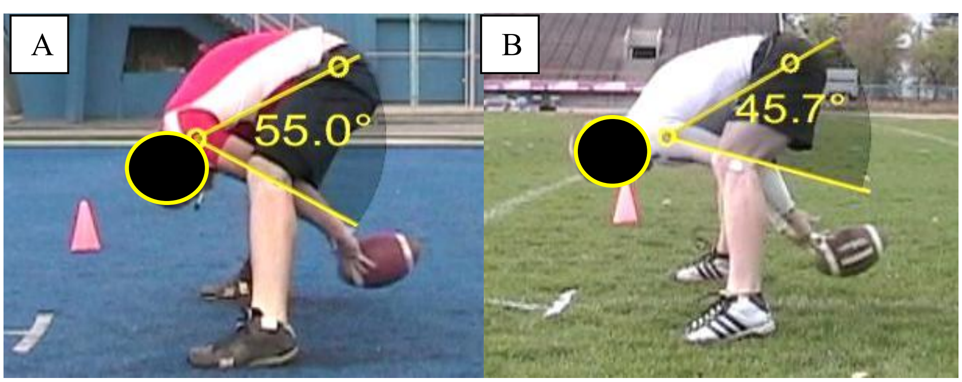


Figure 5.25: Comparison of left shoulder flexion angle at critical instant in two UNI long snappers with release velocities of 14 m/s (A) and 16 m/s (B).

The left shoulder flexion angle in the UNI athlete with a slower release velocity was in fact larger than in the athlete with a faster release velocity. Also in Figure 5.25, the laces of the football are visible in the athlete on the right (B). This was a concern for the researcher since all athletes were thought to be right-handed. The researcher verified the data to see if that this particular athlete was perhaps left-handed or had altered his delivery in another way. The issue here is that this participant did not use the standard grip and started with the laces on the top of the ball under the left hand instead of on the side of the ball under the fingertips of the right hand with flexed wrist. This must have a negative effect on the friction between the pulling fingers of the right hand to give the ball its longitudinal spin or spiral. It was interesting that this athlete had such a high release velocity with this modification to the grip. This particular subject produced fewer revolutions on the football, likely the result of the right hand fingers not being in contact with the laces. This finding may help to explain why angular velocity did not prove to have a significant correlation to release velocity, since some athletes can achieve fast snaps without a fast spiral.

Finally, release height of the football (as %SH) was returned as a possible release velocity predictor in the UNI only regression model. At first, the negative coefficient appears to very high (-15.363), and may suggest large increases in release velocity with small reductions in release height. Recall that release height (given as %SH) was stated in its fractional form (eg. 0.079 instead of 7.9%). This certainly reduces the size of the effect, but still means that by reducing the release height (when stated as a percentage of standing height) from 8.5% to 6%, an increase of 0.5 m/s may be predictable in the release velocity of a UNI long snapper.

Predictors of TST

In the TST regression model for HS and UNI long snappers combined, release angle was the only variable selected from this phase as a predictor of release velocity. With a positive coefficient in the model (+0.023), an increase in release angle would result in an increase in TST. As previously discussed, a higher release angle represents a higher trajectory of the football and less of a direct line path to the punter (Figure 5.23). A decrease in release angle is more of a result of greater velocity (rather than a predictor), which will ultimately decrease TST and improve long snap performance.

Follow Through

Following the critical instant or release of the football, the athlete will continue their movements into the follow through phase of the long snap. The main purpose of the follow through is to slow down the swinging arms. The follow through also allows the long snapper to recover quickly to a position in which they can assume the blocking position required without risking injury to the eccentrically contracting muscles attempting to slow the recently accelerated limbs. The shoulders continue to medially rotate and the forearms pronate to terminal range of motion while the elbows fully extend. The muscles required to slow these movements are the lateral rotators of the shoulder such as supraspinatus, infraspinatus, and teres minor, the supinators of the forearm such as supinator and biceps brachii, and the flexors of the elbow such as brachialis and biceps brachii.

None of the variables measured in the follow through phase were found to have a significant difference between the means of the two groups (*t*-tests). There were also no variables measured in the follow through phase that demonstrated a significant correlation to release velocity in either group (Pearson's product moment correlation). Finally, none of the variables measured in the follow through phase appeared as possible predictors of release velocity in the regression models. The follow through is viewed as an important phase for improving injury reduction, optimizing accuracy, and maximizing velocity at impact. Despite these benefits to the athlete, the follow through phase did not produce any variables helpful for improving snap performance.

Models to Predict Long Snap Release Velocity

Three separate stepwise multiple regression models (Figure 5.26) were devised to predict release velocity in HS only, UNI only, and HS+UNI long snapping subjects. Although the previous discussion has identified the relevant regression model variables from each phase, it is important to look at the complete models rather than one or two of the variables removed from the context of the equation. Multiple regression really allows us to identify a set of predictor variables which when observed together provide a useful estimate of the participant's likely score on the dependent variable (Hassard, 1991). The original proposed study design only called for an HS model and a UNI model when performing the multiple stepwise regression analysis. During the proposal, it was suggested to the researcher to potentially identify key predictors for all the subjects pooled together. It was at this point that a third (HS+UNI) model was added to create the current study design which incorporated each group on its own, as well as all subjects pooled together. In order to verify the equations, the researcher entered the relevant values for several subjects into the regression models. This allowed the researcher to determine the ability of the equation to predict the release velocity by how it compared to the calculated release velocity for that subject in the study. Predicted release velocities were compared to actual release velocities for those subjects and are presented in Table 5.1.

Regression equation for HS long snappers:

$y = +8.324 - 11.350x_1 + 0.150x - 0.057x_3$

Where:
Intercept = +8.324
y = Release Velocity
x_1= Total Snap Time (seconds)
x_2= Backswing Hip Flexion (degrees)
x_3= Backswing Knee Flexion (degrees)

Regression equation for UNI long snappers:

$y = +23.530 - 8.428x_1 - 0.004x_2 + 0.026x_3 - 15.363x_4$

Where:
Intercept = +23.530
y = Release Velocity
x_1 = Total Snap Time (seconds)
x_2 = Critical Instant Left Shoulder Flexion (degrees)
x_3 = Maximum Left Elbow Flexion (degrees)
x_4 = Release Height of ball (as % of Standing Height)

Regression equation for HS and UNI long snappers:

$y = +17.438 - 8.201x_1 + 3.180x_2 + 0.022x_3 - 0.021x_4$

Where:
Intercept = +17.438
y = Release Velocity
x_1 = Total Snap Time (seconds)
x_2 = Subject's Height (m)
x_3 = Left Elbow Flexion Range of Motion (degrees)
x_4 = Backswing Right Elbow Flexion (°)

Figure 5.26: Comparison of the three models to predict release velocity in the long snap.

Table 5.1: Results of the regression models when comparing predicted to actual velocities.

HS ONLY SUBJECTS	**HS3**	**HS4**	**HS5**
Predicted Release Velocity (m/s)	**13.11**	**12.25**	**16.39**
Actual Release Velocity (m/s)	**13.00**	**12.14**	**16.46**

UNI ONLY SUBJECTS	**UNI1**	**UNI2**	**UNI3**
Predicted Release Velocity (m/s)	**15.76**	**14.88**	**13.86**
Actual Release Velocity (m/s)	**16.11**	**14.44**	**13.89**

HS+UNI SUBJECTS	**HS6**	**HS9**	**UNI8**	**UNI10**
Predicted Release Velocity (m/s)	**12.74**	**12.57**	**14.88**	**15.98**
Actual Release Velocity (m/s)	**12.96**	**12.50**	**15.27**	**16.02**

The three stepwise regression models were successful at predicting release velocity accurately within the study subjects. The largest difference between actual and predicted value was 0.44 m/s (UNI2 in UNI only model), and the smallest difference between actual and predicted value was 0.03 m/s (UNI3 in UNI only model). This means the predictor models were 97% to 99.8% successful at predicting actual release velocities based on the three or four variables selected as predictors. This researcher found the performance of the regression models was acceptable and it would be interesting to test them further with more subjects. They appear to be a promising method of identifying key predictors of long snapping performance from a coaching standpoint.

Football coaches can apply this type of research study by using the results of the group to improve individual high school or university long snappers. If recurring results are found (e.g. the right arm is nearly fully extended in the set position in subjects with higher release velocity), then it could be one of the first things coaches can look for in their team's snapper(s). The correlation and regression statistics are useful in identifying how the athlete's skill level may affect their technique. A high school coach's application of the HS regression models may lead to recruiting taller athletes with good knee and hip flexion in the ready position. A university coach's application of the UNI regression models may lead to recruiting taller athletes with more developed shoulder and elbow extensors who are able to release the ball as close to the ground as possible.

The results of the study may introduce or confirm a coach's methods by helping him/her to understand the mechanics behind successful trials. Due to the multiple talents required by a successful football long snapper, coaches must also consider the athlete's ability to block effectively, cover forty yards at full speed, and execute tackles. The benefit of this study to coaches is limited to the mechanics of the delivery, and does not assess the entirety of a long snapper's skill set.

Model to Predict Long Snap Total Snap Time

Within the previous three regression models, TST dominated the model because of the close relationship between release velocity and TST. This placed limitations on the release velocity regression model due to the overpowering predictive power of TST on release velocity and may have clouded other important variables. By performing a stepwise regression analysis to predict TST instead of release velocity (and excluding release velocity from the model), the researcher confirmed the importance of the left elbow extension range of motion. This model also uncovered the contribution of right shoulder medial rotation range of motion as a possible predictor of performance.

The predictive ability of the TST regression model (Figure 5.27) was also tested by comparing predicted values with actual values. The same four subjects were used as in the HS + UNI release velocity model and the results of the comparison are presented in Table 5.2. The total snap time regression model was successful at predicting TST accurately within the study subjects. The largest difference between actual and predicted value was 0.078 seconds (HS9 and UNI10), and the smallest difference between actual and predicted value was 0.001 seconds (UNI8). This means the TST predictor model was 93% to 99.9% successful at predicting actual TST based on the three variables selected as predictors. Once again, this researcher finds the performance of this final regression model as acceptable and it appears to be a reliable method of identifying key predictors of TST, where TST is the ultimate variable that long snappers are attempting to reduce.

TST Regression equation for HS and UNI long snappers:

$y = +0.787 + 0.023x_1 - 0.003x_2 + 0.006x_3$

Where:

Intercept = +0.787

y = TST

X_1 = Release Angle of Ball (°)

X_2 = Left Elbow Extension ROM (°)

X_3 = Right Shoulder Medial Rotation ROM (°)

Figure 5.27: Regression equation to predict HS or UNI long snapper TST.

Table 5.2: Results of the TST regression model when comparing predicted to actual times.

HS+UNI SUBJECTS	**HS6**	**HS9**	**UNI8**	**UNI10**
Predicted TST (sec)	**1.260**	**1.329**	**1.099**	**0.972**
Actual TST (sec)	**1.267**	**1.251**	**1.100**	**1.050**

Chapter 6

Summary, Conclusions, and Recommendations

Summary

The long snap is a specialized football skill that must be performed without error in less than three tenths of a second when snapping to the punter. The quality of the team's long snapper can be one of the determining factors of a squad's success by the special teams. The long snapper must be able to deliver a fast and accurate football with a difficult backwards two-handed throw between his legs to the team's punter, who will then attempt to kick the ball down the field as far as possible. The purpose of the study was to determine the kinematic differences between the long snap to punter when executed by high school (HS) athletes and the long snap executed by university (UNI) athletes. The study also proposed to determine variables that were related to increased release velocity, as well as possible predictors of release velocity in long snappers.

These objectives were tested through a biomechanical investigation in which key kinematic (movement) variables were associated with maximizing the athlete's long snap release velocity. Digital video analysis was performed on both HS and UNI long snappers by measuring key variables and performing statistical analyses on the collected data. It was hypothesized that the release velocity would be greater in the UNI group than in the HS group. It was also hypothesized that the kinematic variables in the UNI group which were related to release velocity would differ from the significant movement variables related to release velocity in the HS group. The secondary hypothesis stated that there would be differences in the measured variables but did not predict which variables would be different. There were also three regression models designed to utilize variables measured during skill performance to predict release velocity. These models were designed for the following groups: HS group only, UNI group only, and HS + UNI groups combined together.

Data was collected from 20 male subjects during nine separate filming sessions. A four camera set up was used to capture the skill, collecting data from sagittal right, sagittal left, sagittal wide and front views. Eighty-three variables were measured at various points during the performance of the long snap. Eight variables were measured during the preliminary movements phase, eight during backswing, thirty-seven during force production, twenty-five at critical instant and five during the follow through phase. The variables were measured with the help of Dartfish Team Pro 4.5.2 Digital Video Analysis Software (Dartfish, 2008). These variables included but were not limited to: angles of the trunk, hip, knee, ankle, shoulders, elbows, angular velocities for elbow, shoulder, hip and knee extension, stance width, release time, total snap time, release height and linear velocity of the ball at release. The data collected allowed the researcher to analyze several aspects of the delivery technique of the snap and to determine where differences occurred between the two groups when performing the skill. Statistical analyses were performed on the measured variables through the use of *t*-tests, Pearson's product-moment correlations, and forward stepwise multiple regression analyses.

The statistical analysis of the means of the two groups revealed several differences in long snapping technique with the majority of the differences occurring during force production or at critical instant of the long snap. Independent *t*-tests were performed in order to determine the kinematic differences in long snapping technique between the high school and university athletes as described as one of the purposes of the study. Differences were only determined to be significant if they demonstrated p-values ≤ 0.0105, which was the critical p-value determined with the false discovery rate (FDR) adjustment.

In the preliminary movements phase, none of the measured variables were found to be significantly different between the high school and university groups. It was observed that the UNI athletes appeared to demonstrate greater hamstring flexibility, but the difference was not found to be significant. A finding of a significant difference would have supported previous studies (Davis et al, 2004, Pratt, 1989) that have reported the maintenance or improvement of flexibility from high school to university football players. Although nearing significance with the UNI athletes appearing to be more flexible than the HS athletes, the groups did not differ statistically in their measures of hamstring flexibility.

In the backswing phase, the statistical analysis did not return any significantly different variables when the high school and university long snappers were compared in the backswing phase. Although individual subjects showed large variations in their backswing (pre-load) position kinematic variables, the group means were not significantly different. This study does not support Blegen et al's (2006) claim that UNI level long snappers demonstrate greater shoulder flexion and elbow extension in the backswing phase, although elbow extension position does appear to be highly related to release velocity. This is interesting since HS and UNI release velocities were found to be significantly different in the study, yet none of the backswing variables (including those highly correlated to release velocity) were found to be significantly different between the groups.

Of the 37 variables that were measured in the force production phase (Table 4.5), three were found to be significantly different between the high school and university groups. The variables identified as statistically different between the groups were maximum angle of left elbow flexion (prior to elbow extension), left elbow extension range of motion, and left elbow extension velocity.

All subjects in the study released the football with nearly fully extended elbows, but as previously discussed the UNI athletes demonstrated higher left elbow flexion angles. This increased flexion at the elbow prior to extension resulted in the UNI group moving through a larger range of motion at the elbow than the HS group. This is likely a benefit to force production provided the athlete can apply constant or increasing force through that range of motion. The UNI group was able to apply greater force to the football than the HS group which is evident by a significantly larger mean left elbow extension velocity during force production.

The majority of the differences between the two groups of long snappers were discovered during the critical instant phase. Nine of twenty-five variables were found to be significantly different between the two groups (Table 4.6), and included: right heel distance covered, left heel distance covered, total distance covered (average of both feet), total flight time of the football (TFT), total snap time (TST), absolute release height of the football, relative release height of the football (% standing height), release velocity of the football, and average velocity of the football.

The UNI group moved backward a greater distance than the HS group as they released the football. This sliding, or "airborne" phase appears to be an important marker of long snapping skill level. More forceful knee extension and ankle plantarflexion will assist in moving the centre of gravity backwards (superior and posterior relative to the starting point).

The UNI group was able to produce lesser TFT and TST than the HS group in the study. These two variables go hand in hand since TST = TFT + release time, and the differences between subjects' release times were relatively small. It was interesting to note that the UNI group actually had slightly higher release times, supporting the theory that more time in force production will create a larger impulse and result in an increased release velocity of the ball (or decreased TFT).

The HS long snappers release the football higher than the UNI long snappers. This higher release height makes it difficult to keep the release angle down. This difference is likely due to less muscular development and/or less hamstring flexibility in the HS group. The UNI subjects were able to demonstrate greater release velocities and subsequently greater average football velocities than the HS long snappers. This supports the primary hypothesis that UNI athletes would demonstrate higher velocities than the HS group due to increased strength, age, and physical maturation.

In the follow through phase, none of the measured variables were found to be significantly different between the high school and university groups. Due to the restrictive body position in long snapping, this was not surprising. The shoulder extension is limited by arm/leg contact, the elbows are nearly fully extended at release, and the forearms pronate to the end of their range of motion. The follow through phase of the long snap is also restricted in game situations since the snapper must quickly recover to a stand up position in order to execute their blocking duties before running down field for coverage.

A correlation analysis was conducted on all the measured kinematic variables to determine which variables were significantly correlated to each of the long snappers' respective release velocities. This statistical test allowed the researcher to address the secondary purpose of the study by determining which variables may be key contributors to release velocity performance for the two groups separately. This is helpful to coaches in improving release velocity of long snappers with specific movement adjustments.

The results of the high school correlation analysis determined six of the variables to be significantly related to a HS long snapper's release velocity with a p-value ≤ 0.05 (Table 4.8), and two variables nearing significance with a p-value ≤ 0.06. These variables, in order of significance, and also stated as a positive (+) or negative (-) relationship to release velocity, were: total snap time (-), right elbow flexion in the backswing (set position) (-), release height when given as a percentage of standing height (-), release angle of the football (-), right forearm pronation range of motion (force production) (-), left forearm pronation range of motion (force production) (-), left elbow extension velocity (force production) (+), and total distance covered backwards through critical instant (average of both feet) (+).

The results of the university correlation analysis determined that six of the variables were significantly related to a UNI long snapper's release velocity with a p-value ≤ 0.05 (Table 4.9), and two variables nearing significance with a p-value ≤ 0.08. These variables, in order of significance, and also stated as a positive (+) or negative (-) relationship to release velocity, were: total snap time (-), angular velocity of the football (+), release angle of the football (-), maximum left elbow flexion (prior to force production) (+), right elbow extension range of motion (force production) (+), maximum right elbow flexion (prior to force production) (+), right elbow flexion angle in backswing (set position) (-), and right elbow extension velocity (force production) (+).

A forward stepwise multiple regression analysis was conducted to determine which variables were the most significant possible predictors of long snapping release velocity. Forward stepwise multiple regression models were created which allowed the researcher to address the secondary purpose of the study which was to determine the most important body movements and body positions that may be able to predict release velocity. Separate regression equations were modeled for the high school group, the university group, as well as the HS + UNI groups combined.

The regression equation to predict the high school long snapper's release velocity included three variables that explained 98.7% of the variance in release velocity between the subjects. These variables included: total snap time, hip flexion angle (in backswing), and knee flexion angle (in backswing). This was the most successful regression model in that it not only returned the highest r-squared value (0.987), but it included variables that could all be estimated with very little equipment or assistance.

The regression equation to predict the university long snapper's release velocity included four variables that explained 92.8% of the variance in release velocity between the subjects. These variables included: total snap time, shoulder flexion angle (at critical instant), maximum left elbow flexion angle (prior to force production), and release height of the ball reported as a percentage of the athlete's standing height. This was the least successful of the three regression models in that it returned an r-squared value of 0.928 which means there was nearly 10% of unexplained variance within the UNI group. This model also included variables that would be difficult to estimate without video recording equipment or biomechanical analysis software.

The regression equation to predict the release velocity of all long snappers involved in the study (HS + UNI groups combined) included four variables that explained 96.9% of the variance in release velocity among all subjects. These variables included: total snap time, height of the subject, left elbow extension range of motion (force production), and right elbow flexion angle in backswing (set position). This is perhaps the most interesting model since it predicts long snapping release velocity regardless of skill level.

Conclusions

Based on the findings of this study, the following conclusions appear to be justified:

1. Release velocity was significantly greater in favour of the university long snappers. Average velocity of the football was also significantly greater in the university athletes which means their snaps were traveling in a more direct line towards the punter than the higher arcing trajectories demonstrated by the high school long snappers.
2. University athletes appear to be more skilled at involving the left (non-dominant) arm in the snapping motion. They not only utilize a significantly greater range of motion at the left elbow during its extension (caused mainly by significantly higher maximum left elbow flexion prior to extension), but are able to achieve significantly greater elbow extension velocity than high school long snappers.
3. University athletes move a significantly greater distance backward towards the punter during the airborne phase of the long snap. The measurements of the displacement of each foot, and the average of both feet, support this statement.

4. University long snappers had significantly shorter total flight times of the football, as well as total snap times despite taking slightly longer to release the football.
5. University long snappers release the football lower than high school athletes. This statement holds true even when the subject's height is taken into consideration and the release height is stated as a percentage of standing height.
6. High school and university athletes who set up with less right elbow flexion in the backswing position were able to achieve significantly higher release velocity.
7. High school long snappers that pronated the forearms less prior to release were able to achieve significantly greater release velocity. Lower release heights and lower release angles were associated with greater release velocity in long snappers, and it is apparent that decreasing release height would lower release angle as well as forearm pronation and shoulder medial rotation.
8. High school long snappers that involved the left arm more in their force production phase (or demonstrated higher left elbow extension velocity) were able to achieve significantly greater release velocity.
9. Taller long snappers (regardless of skill level) appear to have an advantage in achieving greater release velocity.

Recommendations

The following recommendations are suggested for future studies conducted on the long snap in football:

1. Future studies should include professional level athletes in order to understand the kinematic progression of the long snap to the highest skill level.
2. Future studies should incorporate the use of accelerometers or three-dimensional analysis software for more accurate measurement of shoulder medial rotation, as well as forearm pronation range of motion and velocity.
3. Future studies must include a greater number of subjects to ensure significant results (when differences are present) and to allow for valid generalization of the findings to the long snapping population.
4. Future studies should incorporate accuracy as a measurable variable due to its importance in the long snap. A scoring system should be devised to give the researcher the ability to rate accuracy and include it in the statistical analysis.
5. Future studies should consider the inclusion of an accurate measure of the athlete's strength and flexibility to verify the importance and weighting of these variables when analyzing the skill.
6. Future studies may consider the observation of whether long snappers alter their stance between parallel and non-parallel depending on the circumstances.

Coaching Recommendations

The long snapper, in both high school and university football teams, plays an important role in the success of the special teams. During an athlete's development it is important that coaches and athletes understand the effects of specific technical flaws. The earlier these errors are detected and addressed, the sooner the athlete can progress to their desired level of competition. The following coaching recommendations have been made based on the significant findings of this study and should be pointed out to coaches as being important to skilled long snappers:

1. The body position in the backswing (set position) should be such that the elbows (particularly the right or dominant throwing side) are almost fully extended placing the football ahead of the long snapper, and not under the head of the athlete. Increased shoulder flexion, knee flexion and horizontal positioning of the trunk make it easier to achieve this position.
2. Long snappers should extend the knees and plantarflex the ankles forcefully enough to initiate backward and upward movement of the athlete's body (airborne phase).
3. Once the force production phase is initiated, the long snapper should flex the elbows as much as 90° prior to extending them. Elbow extension begins when the arms contact the legs after forceful shoulder extension.

4. Long snappers should focus on minimizing release height and release angle of the football by maintaining a more horizontal trunk position, maximizing the airborne phase, and reaching back toward the punter through delivery. Athletes who are physically under-developed will have difficulty making these adjustments due to the greater strength required for a lower release.

5. High school long snappers should consider increasing hamstring flexibility as a possible method of improving their mechanics in hopes of increasing release velocity.

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Appendix A

Ethics Approval Certificate

CTC Building
208 - 194 Dafoe Road
Winnipeg, MB R3T 2N2
Fax (204) 269-7173
www.umanitoba.ca/research

UNIVERSITY OF MANITOBA | OFFICE OF RESEARCH SERVICES
Office of the Vice-President (Research)

APPROVAL CERTIFICATE

05 March 2009

TO: **Michael George Chizewski** (Advisor: M. Alexander)
Principal Investigator

FROM: **Stan Straw, Chair** [redacted]
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2009:015**
"A Biomechanical Comparison of the Long Snap to Punter between High School and University Football Players"

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **if you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to Eveline Saurette in the Office of Research Services (fax 261-0325, phone 480-1409), including the Sponsor name, before your account can be opened.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/ors/ethics/ors_ethics_human_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

Bringing Research to Life

Appendix B

Informed Consent

UNIVERSITY OF MANITOBA

INFORMED CONSENT

Research Project Title: A Biomechanical Comparison of the Long Snap to Punter between High School and University Level Football Players.

Researcher: Michael Chizewski (B.P.E) **Advisor:** Dr. Marion J.L. Alexander

University of Manitoba Sport Biomechanics Laboratory
Faculty of Kinesiology and Recreation Management
Health, Leisure and Human Performance Research Institute
316 Max Bell Centre, Winnipeg, Manitoba, Canada, R3T 2N2

This consent form, a copy of which will be left with you for your records upon request, is only part of the process of informed consent. It should give you the basic information on what the research is concerned with and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

PURPOSE OF THE STUDY

The purpose of this study is to examine the long snapping techniques of individual athletes from varying skill levels, in order to determine the key movements of long snapping technique and assist coaches in improving the technique of distance snappers. The subjects are either currently a member of a high school or university/junior team in Canada, or are considered to be a prospect for membership in these programs.

METHODOLOGY

Subjects will be filmed during pre-arranged filming sessions held at the University of Manitoba or team practice facilities. Equipment from the University of Manitoba Biomechanics Laboratory will be used. After customary warm-up, subjects will be instructed to perform ten (10) long snaps at a target. The target will be placed at a distance of 12.8 m. Informed consent must be obtained for the study prior to filming. All filming procedures will be organized and administered by the graduate student and principal researcher, Michael Chizewski.

When filming is completed, the videos will be analyzed by the principal researcher working on the project. The types and ranges of motion in each of the skills, as well as selected linear and angular velocities in each of the skills will be described. Still images taken (or pulled from the video footage) may be used within the researcher's written Master's thesis, as well as the oral proposal; however the identity of the athlete will be concealed for confidentiality. The technique descriptions developed from this analysis and pictures developed from the video may eventually be published in a thesis titled "A biomechanical comparison of the long snap to punter between high school and university football players."

RISK

There is no additional risk involved in this study, as you will perform the skills as you would normally perform them in a practice or game situation without the opposing player contact that normally follows the skill. The cameras will be at least 2.0 m from the athletes, and will not interfere with the performance of the skill.

CONFIDENTIALITY

Confidentiality of the subjects will be maintained by assigning video clips an identification number, instead of being associated with the athlete's name. Raw forms and data will be stored in a locked filing cabinet in the Biomechanics Laboratory at the University of Manitoba. Video clips used for analysis will be stored on a laptop that is password protected. Only the principal researcher and graduate advisor will have access to the athlete's information and video. Still pictures or video clips may be used in the final thesis document and oral thesis defense. Identity of the athlete will be obscured pictures and video to aid in confidentiality. The school, team or athlete will not be identified in either the written thesis or oral defense. A copy of each athlete's raw footage and study results will only be made available to the athlete. The researcher will provide each athlete with the opportunity to request the information on the letters of consent/assent. Coaches will not have direct access to the information via the researcher unless the player indicates that this is acceptable through written permission to the principal researcher.

PARTICIPATION

Your participation in this study is voluntary, you may decline to participate. If you decide to participate, you may withdraw from the study at any time without penalty or question. You are free to refrain from answering any questions you prefer to omit, without prejudice or consequence. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. If you withdraw from the study prior to its completion, your data will be returned to you or destroyed.

CONSENT

I have read and understand the above information. I agree to participate in the study.

In the event that the participant is under 18 years of age, a letter of assent will be provided to them as well as a copy of this consent form, which will be the same form signed by their respective parent or guardian. Both forms (consent and assent) must be signed and returned to the principal researcher prior to filming.

____________________ ____________________ ________
Participant's name (print) **Signature** **Date**

____________________ ____________________ ________
Parent/Guardian **Signature** **Date**
(if under 18 years of age)

____________________ ____________________ ________
Researcher and/or Delegate **Signature** **Date**

***To be checked only by the athlete / participant.**

☐ **Yes, I would like a digital copy of my personal raw footage and study results.**
(Please provide a telephone number and mailing address on the back of this page)

☐ **No, I do not require a digital copy of my personal raw footage and study results.**

(Reminder: This box is only to be checked by the athlete, since the digital raw skill footage will only be released to the athlete unless written permission is provided to the principal researcher by the athlete.)

This research has been approved by the Education/Nursing Research Ethics Board at the University of Manitoba. If you have any concerns or complaints about this project you may contact any of the persons listed below or contact the Human Ethics Secretariat, Maggie Bowman, at 474-7122, or e-mail margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Appendix C

Letter of Assent

Faculty of Kinesiology &
Recreation Management
316 Max Bell Centre
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-6875

Letter of Assent

Date of distribution.

Dear athlete,

I am a Master of Science student in the Faculty of Kinesiology and Recreation Management at the University of Manitoba. I am beginning the data collection for my Master's thesis, entitled "A biomechanical comparison of the long snap to punter between high school and university level football players" and am requesting your participation as a long snapping specialist.

The study will look at high school and university football players and attempt to identify the key biomechanical or technical differences (if any) between the two levels of players. This will be done by recruiting and filming ten high school and ten university players who will specialize in the long snap. I will be asking you to perform 10 long snaps while I film the skill for analysis. The session, including warm-up will take less than 30 minutes. Your parent or legal guardian has already given permission for you to participate in this study, but you do not have to participate if you choose not to. You may quit the study at any time by simply saying "Stop" or "I no longer wish to participate". There are no known risks involved in this study beyond the normal performance of the skill that you to perform in practice or game situations. If you would like a copy of the video data (check below), a digital copy of your raw video footage will be provided to you by the researcher. Your coaches or parents will not be given a copy of the footage, unless you give written permission to the researcher to do so, or decide to share it with them.

If you have any questions about this study, please feel free to contact me directly.

Sincerely yours,

Michael G. Chizewski — University of Manitoba Sport Biomechanics
Phone: 204-474-6875 — Email: mgcbiomechanics@gmail.com

I agree to participate in this research project and I have received a copy of this form.

____
Participant's Name (Please Print)

____
Participant's Signature *Date*

***To be checked only by the athlete / participant.**

☐ **Yes, I would like a digital copy of my personal raw skill footage.**
(Please provide a telephone number and mailing address on the back of this page)

☐ **No, I do not require a digital copy of my personal raw skill footage.**

Appendix D

Pilot Study

Pilot study

Introduction

The primary purpose of the pilot study was to identify the key differences in the kinematic variables affecting long snap velocity of accurately delivered footballs between two players of varying skill level that could be considered in this study. The secondary purpose of the pilot study is to identify all the important variables that are necessary to produce a complete description of this unique skill. The pilot study served to implement and practice appropriate filming technique and protocol for future study by the researcher on this topic.

Filming for the pilot study was conducted on two separate occasions. University long snaps were filmed on August 30, 2008 at Pan-Am Stadium (University of Manitoba) in Winnipeg, Manitoba. High school long snaps were filmed on September 5, 2008 at St. Paul's High School in Winnipeg, Manitoba.

Methods

Subjects

Two male subjects aged 17 and 24, were recruited for the pilot study. Subject 1 (HS) was recruited from the St. Paul's High School AAA team, a member of the Winnipeg High School Football League; while Subject 2 (UNI) was recruited from the University of Manitoba Bisons team, a member of the Canadian Interuniversity Sports League. Subjects were filmed on one occasion with their coaches present, and were provided adequate warm up time before the filming began. Subjects (and associated parent / guardian for subjects under 18 years) completed informed consent forms (see Appendix B) prior to filming. Video was imported to a Toshiba A200 laptop and analyzed using Dartfish 4.5.2 Software.

Filming Technique

Four cameras were used to film the long snappers during their performance in order to collect the necessary footage required for variable measures. One Canon GL2 camera was positioned 2 meters directly in front of the subject on a 0.10 meter high tripod. The camera was positioned at an angle (10° to the horizontal) to capture not only the snapping motion, but a clear view of the intended target area. This camera angle was also used to determine the most accurate of the fastest trials for analysis.

The second and third cameras (Canon ZR500 and ZR700) were positioned on either side (to the right and left) of the athlete. These two cameras were placed on 1 meter high tripods, at a distance of 3.5 meters from an imaginary line bisecting the subject in the sagittal plane, and placed 1 m back from the extended line of scrimmage.

The fourth and final camera (Canon HDV 1080i) was positioned on a 1 meter high tripod to one side of the performed skill (the side may differ to allow the camera to face away from the sun) at a distance of 20 meters from the imaginary line bisecting the subject in the sagittal plane. The camera was positioned at the mid-point between the target and the subject to capture the entire flight of the football, as well as the subject and the target.

Cameras were set to record at a minimum shutter speed of $1/1000^{th}$ of a second to maximize clarity of film and accuracy of joint measurements. The front camera was set to record at $1/2000^{th}$ of a second in order to collect the necessary joint angle information to estimate medial rotation of the shoulder and pronation of the forearm.

Filming Protocol

Instruction of filming protocol occurred prior to the beginning of the trials, and no instruction or feedback regarding snapping technique was given to the subjects during the filming. This was to ensure that the investigator did not influence or bias the performance of the subjects during the trials. The only conversation between investigator and subject, once the testing began, was to relay the number of the trial prior to each long snap. The investigator would say the number of the trial that had just been completed, and would state "hit" or "miss" to the subject.

Following sufficient individualized warm-up, the football was placed on the line of scrimmage for the subjects between trials by the investigator or another player. Subjects were asked to approach the ball as they would in a game and assume their individual stance or set-up. Subjects were instructed to perform the snap as they would in a game, as quickly and accurately as possible. Each subject was instructed to perform ten consecutive trials. Between each trial, subjects were asked to leave the line of scrimmage and walk around a designated pylon before returning to the line of scrimmage for the next trial. This provided the researcher with a more accurate measure of the preliminary movements for each trial, since the feet had to be placed in position again before each snap. The subject was instructed to perform the trials at their own pace, with the opportunity for a longer rest between trials if requested.

Digital video analysis

Video analysis was used to accurately measure the qualitative and quantitative information necessary to compare and analyze the biomechanics of the centre's long snap to punter. This comparison was conducted between the high school and university subjects. The complete video analysis was conducted using Dartfish Advanced Video Analysis Software, version 4.5.2.

The analysis investigated the movements of each subject's fastest and most accurate snap attempt from first motion of the body in the preliminary movements phase until the follow through; as well as the motion of the football from the critical instant until reaching the intended target 12.8 m behind the subject. The primary variables of interest were the football's release velocity (measured over the first four to six video frames immediately after release), and the total snap time from the first movement of the subject to the ball reaching a horizontal distance of 12.8 m (14 yards). These variables were positive indicators of the subject's ability to accelerate the football in the direction of the awaiting punter. Sixty three variables of interest were measured; they are presented along with their associated skill phase in Table 1.

Table 1. Variables to be measured in the pilot study.

Phase of the Skill	**Variable(s) Measured**
Preliminary Movements	• Stance width (m) • Stance width (% of standing height) • R heel distance from line of scrimmage (m) • L heel distance from line of scrimmage (m) • Deviation of right foot out-turn from sagittal plane (°) • Deviation of left foot out-turn from sagittal plane (°)
Backswing	• Forward trunk lean (° deviated from horizontal) • R shoulder flexion (°) • L shoulder flexion (°) • R elbow flexion (°) • L elbow flexion (°) • Hip flexion (°) • Knee flexion (°) • Ankle dorsiflexion (°)

Force Production	• Maximum R elbow flexion (°) • Maximum L elbow flexion (°) • R shoulder extension (°/sec) • L shoulder extension (°/sec) • R elbow extension (°/sec) • L elbow extension (°/sec) • Hip extension (°/sec) • Knee extension (°/sec) • Ankle plantarflexion (°/sec)
*Arm/leg contact	• R shoulder medial rotation (°) • L shoulder medial rotation (°) • R forearm pronation (°) • L forearm pronation (°) • R shoulder medial rotation (°/sec) • L shoulder medial rotation (°/sec) • R forearm pronation (°/sec) • L forearm pronation (°/sec)
* Airborne	• Total airborne time (sec.) • R heel distance covered (m) • L heel distance covered (m)
Critical Instant	• Release time (start of movement to release in sec.) • Total flight time (ball in the air in sec.) • Total snap time (start of movement to 12.8 m in sec.) • Time from max. elbow flexion to release (s) • Time from arm / leg contact to release (s) • Release height of football (m) • Release velocity of football (m/s) • Release angle of football (° from horizontal) • Average linear velocity of ball (m/s) • Average angular velocity of ball (°/sec) • Angular momentum of ball ($kg \cdot m^2/s$) • Forward trunk lean (° deviated from horizontal) • R shoulder flexion (°) • L shoulder flexion (°) • R elbow flexion (°) • L elbow flexion (°) • R shoulder medial rotation (°) • L shoulder medial rotation (°) • R forearm pronation (°) • L forearm pronation (°) • Hip flexion (°) • Knee flexion (°) • Ankle plantarflexion (°)
Follow through	• Trunk forward lean (° from horizontal) • Hip flexion (°) • Knee flexion (°) • Shoulder flexion (°) • Shoulder medial rotation (°) • Forearm pronation (°)

Results

The digital video analysis resulted in measured differences and similarities between the two subjects with regard to their mechanics and their ultimate skill performance. All kinematic variables measured in the pilot study are reported in Table 2.

Table 2. Kinematic variables measured in the pilot study.

Phase	Variable	Subject 1 (HS)	Subject 2 (UNI)
Preliminary	Stance width (m)	1.08	1.26
Movements	Stance width (% standing height)	64.42	63.60
	Right heel distance from LOS (m)	0.92	0.81
	Left heel distance from LOS (m)	0.74	0.74
	Right foot angle of out-turn (° from sagittal)	48.3	39.1
	Left foot angle of out-turn (° from sagittal)	40.1	38.9
Backswing	Forward trunk lean (° from horizontal)	17.1	11.2
	Right shoulder flexion (°)	120.6	106.0
	Left shoulder flexion (°)	121.2	98.2
	Right elbow flexion (°)	23.4	24.0
	Left elbow flexion (°)	20.9	21.1
	Hip flexion (°)	146.6	151.8
	Knee flexion (°)	58.6	75.2
	Ankle dorsiflexion (°)	6.7	8.1
Force Production	Maximum right elbow flexion (MEF) (°)	49.3	82.9
	Maximum left elbow flexion (MEF) (°)	38.5	74.5
	Right shoulder extension (°/sec)/(rads/sec)	292.15/5.10	170.29/2.97
	Left shoulder extension (°/sec)/(rads/sec)	271.08/4.73	154.57/2.70
	Right elbow extension (°/sec)/(rads/sec)	416.87/7.28	742.17/12.95
	Left elbow extension (°/sec)/(rads/sec)	350.60/6.12	763.86/13.33
	Hip extension (°/sec)/(rads/sec)	89.26/1.56	-1.43/-0.02
	Knee extension (°/sec)/(rads/sec)	201.24/3.51	61.43/1.07
	Ankle plantarflexion (°/sec)/(rads/sec)	76.86/1.34	26.0/0.45
***Arm/leg contact**	Right shoulder medial rotation (°)	82.7	89.3
	Left shoulder medial rotation (°)	96.3	85.8
	Right forearm pronation (°)	42.6	20.5
	Left forearm pronation (°)	38.1	36.6
	Right shoulder medial rotation (°/sec)/(rads/sec)	137.88/2.41	90.91/1.59
	Left shoulder medial rotation (°/sec)/(rads/sec)	330.31/5.76	263.64/4.60
	Right forearm pronation (°/sec)/(rads/sec)	65.15/1.14	24.24/0.42
	Left forearm pronation (°/sec)/(rads/sec)	103.03/1.80	45.45/0.79
*** Airborne**	Total airborne time (seconds)	0.133	0.133
	Right heel distance covered (m)	0.11	0.22
	Left heel distance covered (m)	0.10	0.15

Critical Instant	Release time (RT) (seconds)	0.242	0.350
	Total flight time of ball (TFT) (seconds)	1.059	0.851
	Total snap time (TST) (seconds)	1.301	1.201
	Time from MEF to critical instant (s)	0.083	0.083
	Time from arm/leg contact to critical instant (s)	0.066	0.033
	Release height of ball (m)	0.22	0.17
	Release velocity of ball (m/s)	12.69	15.17
	Release angle of ball (° from horizontal)	22.6	16.2
	Average linear velocity of ball (m/s)	12.09	15.04
	Average angular velocity of ball (°/sec)/(rads/sec)	2787.61/48.65	2538.19/44.30
	Angular momentum of ball (kg•m^2/sec)	0.104	0.095
	Forward trunk lean (° from horizontal)	29.1	26.7
	Right shoulder flexion (°)	49.9	46.4
	Left shoulder flexion (°)	55.6	44.1
	Right elbow flexion (°)	14.7	21.3
	Left elbow flexion (°)	9.4	11.1
	Right shoulder medial rotation (°)	91.8	92.3
	Left shoulder medial rotation (°)	118.1	94.5
	Right forearm pronation (°)	46.9	21.3
	Left forearm pronation (°)	44.9	38.1
	Hip flexion (°)	125.0	152.3
	Knee flexion (°)	8.5	53.7
	Ankle plantarflexion (°)	11.9	1.0
Follow Through	Forward trunk lean (° from horizontal)	31.2	44.3
	Hip flexion (°)	125.8	169.1
	Knee flexion (°)	9.9	44.7
	Shoulder flexion (°)	51.5	48.6
	Right shoulder medial rotation (°)	109.5	94.7
	Left shoulder medial rotation (°)	122.1	104.5
	Right forearm pronation (°)	49.2	60.5
	Left forearm pronation (°)	35.4	69.7

The HS release velocity of the football was calculated at 12.69 m/s while the UNI release velocity was calculated at 15.17 m/s. Total snap times (TST) for the subjects were calculated at 1.301 seconds (HS) and 1.201 seconds (UNI) over the same snapping distance of 12.8 m. This initial measure of the dependent variable (release velocity) suggests that university athletes are able to produce greater release velocities and shorter snap times than high school athletes.

It is interesting to note that although the university subject had a shorter TST, his release time (RT) was 44.63% longer than the high school subject. RT was measured as the time from first movement of the athlete from the ready position to critical instant; and was calculated at 0.242 seconds (HS) and 0.350 (UNI). The extra 0.108 seconds allows the university snapper to apply force to the ball for an extended period of time. The university snapper also demonstrated much greater maximum elbow flexion (MEF) prior to the elbow extending during force production. UNI right and left MEF were 82.9° and 74.5°, while HS right and left MEF were 49.3° and 38.5°. This longer force application over a greater range of motion results in a greater linear impulse being produced, and a subsequent greater change in the football's linear momentum (demonstrated by the increase in UNI release velocity and decreased UNI total flight time (TFT) of the football).

Blegen et al (2005) suggested that more skilled long snappers will place the ball further in front of the head in the backswing position with greater shoulder flexion and elbow extension than less skilled snappers. Pilot data measured right shoulder flexion in the backswing at 120.6° (HS) and 106.0° (UNI); and left shoulder flexion in the backswing at 121.2° (HS) and 98.2° (UNI). Elbow flexion for both arms of both subjects was nearly identical at 23.4°/20.9° (HS) and 24.0°/21.1° (UNI). The university subject was also taller (1.98m) than the high school subject (1.68m), and setup at the same distance from the line of scrimmage. This demonstrates the university snapper had less shoulder flexion than the high school subject, and the football was positioned much closer than recommended to a line drawn straight down from the head as opposed to in front of the body.

Another suggestion from Blegen et al (2005) was that more skilled long snappers would slide back farther than less skilled snappers during the airborne phase of delivery.

Pilot data showed the same airborne times for HS and UNI subjects (0.133 seconds), but showed the university athlete moving backwards 0.22 m and 0.15 m with his right and left heel respectively. The high school athlete over the same time frame moved backwards less at 0.11 m and 0.10 m (right and left heels).

Harrington (2003) suggested that more skilled long snappers may assume a more horizontal positioning of the trunk throughout the skill. Pilot data indicates UNI forward trunk lean to be less than HS, with measures of 11.2° (UNI) and 17.1° (HS) during the backswing (this angle is the degree of downward deviation from horizontal). UNI forward trunk lean is also slightly less than HS at critical instant, with measures of 26.7° (UNI) and 29.1° (HS). These results suggest the university player does maintain a more horizontal positioning of the trunk, though it may not be significant in the pilot measures. It was also observed during pilot analysis that the UNI subject follow through took him to a forward trunk lean position of 44.3°, while the HS subject follow through forward trunk lean was 31.2°. Although maintaining a horizontal position from force production, the university subject continued the range of motion further than the high school subject.

Other variables that showed potentially significant differences were: knee flexion, hip extension velocity through force production, release angle of the football, and average velocity of the football. UNI knee flexion was 75.2° in the backswing, with HS knee flexion measured at 58.6°. Subsequent measures of knee flexion at critical instant show UNI knee flexion at 53.7°, and HS knee flexion at 8.5°. The university subject retained much more of the flexion in his knees, while the high school was nearly in full knee extension at critical instant. Along with greater knee extension, HS hip extension was also greater as the HS hip flexion measures ranged from 146.6° to 125.0° through force production. UNI hip flexion actually increased slightly from 151.8° to 152.3°, demonstrating little or no movement at the hip joint. Since the hip was measured to have flexed slightly, hip extension is given in Table 2 as a negative number (to represent hip flexion as the hip extension value in the university subject).

The UNI release angle was 16.2° from the horizontal while the HS release angle was 22.6°. This suggests the high school subject delivers the football with more vertical velocity resulting in a higher arcing parabolic path, contributing to the longer time in the air. A higher parabola means the football must cover a greater absolute distance when covering the same horizontal distance, and will not only be in the air longer, but will likely demonstrate a greater discrepancy between the football's release velocity and its average velocity. Henrici (1967) stated one of the main goals of the long snapper is to attempt to achieve similar average and release velocity values. Pilot data demonstrated this with HS average velocity being 0.60 m/s less than release velocity; converting to a 4.73% decrease. UNI average velocity was only 0.13 m/s less than release velocity; converting to a 0.86% difference in the two velocities. This is achieved by the flatter release angle and greater impulse achieved by the university snapper.

An interesting result was that although the university subject's snap had a greater linear velocity, the HS angular velocity of the football (48.65 rads/s) was slightly greater than the UNI angular velocity (44.30 rads/s). Since the angular velocity was calculated by counting the revolutions of the football, the researcher is confident that this variable measurement is valid and reliable. The question raised from this finding was whether the analysis estimation of shoulder medial rotation and forearm pronation would support the finding. Pilot data analysis did, in fact, show the HS shoulder medial rotation (SMR) velocities and forearm pronation (FP) velocities (right and left) to be greater than UNI shoulder medial rotation and forearm pronation velocities. The high school subject was measured at 2.41 and 5.76 rad/s (HS right and left SMR), also at 1.14 and 1.80 rad/s (HS right and left FP). The university subject was measured at 1.59 and 4.60 rad/s (UNI right and left SMR), also at 0.42 and 0.79 rads/s (UNI right and left FP).

Discussion

The primary purpose of the pilot study was to ensure that all of the proposed variables were measurable and visible from the camera views. Also the pilot study could identify the differences in the kinematic variables affecting the velocity of accurately delivered long snaps between two players of potentially different skill levels. Pilot data analysis indicates that significant differences may exist between high school and university long snappers, in variables such as: release velocity of the football, total snap time, release time, release angle, maximum elbow flexion, shoulder flexion in backswing, forward trunk lean, horizontal distance covered while airborne, hip flexion, knee flexion, and relative difference between release velocity and average linear velocity. These differences support the rationale to further analyze and describe this under-reported skill to contribute to current knowledge of the long snap.

The secondary purpose of the pilot study was to identify all possible variables necessary in creating a complete and comprehensive description of the long snap to punter. Sixty three potential variables were identified and measured in the pilot data. An analysis of this considerable detail has never been reported in the literature, so it was difficult to remove potentially insignificant variables based on related research reports. Until adequate numbers of subjects can be recruited, filmed, and analyzed, all variables must be included before being statistically eliminated from further study.

The pilot study was meant to serve to implement and refine appropriate filming technique and protocol for the study. Pilot data collection has provided useful practice in establishing protocol distance measures and guidelines, which will be implemented in the research. The camera angles chosen for filming technique provided adequate footage from which to analyze the movement.

Although fewer variables are measured from the front camera, it was deemed to be a necessary angle. This view not only provides the researcher with a front view of the football's path to be able to assess accuracy, but provides critical data for estimations of shoulder medial rotation and forearm pronation. The pilot study also allowed for modifications (addition) to the joint marking of the subjects for these measurements. The researcher decided not only to mark the joint centres, but also to place strips of reflective tape on the humerus and the lower arm to help in consistently identifying rotational landmarks. The strip on the humerus was to be placed vertically along the deltoid tuberosity to the lateral epicondyle. The second strip was to be placed along the lateral border of the radius to the radial styloid process.

It is clear that further study of the centre's long snap to punter is necessary before definitive statements can be made regarding biomechanical and kinematic variables, and their significance to performance of the skill. This researcher is eager to recruit more subjects who specialize in the long snap, which may in turn allow for useful conclusions and further recommendations to be made to interested coaches and educators.

Appendix E

Subject Characteristics

Subject Characteristics

Subject	Variables		
High School (HS)	**Age (years)**	**Height (m)**	**Weight (kg)**
HS1	17	1.91	104.33
HS2	16	1.78	63.50
HS3	17	1.78	83.70
HS4	17	1.89	101.60
HS5	17	1.84	91.40
HS6	18	1.82	83.92
HS7	17	1.80	88.45
HS8	17	1.73	68.04
HS9	17	1.68	104.33
HS10	18	1.93	100.25
Mean HS	17.10	1.82	88.95
University (UNI)			
UNI1	23	1.93	108.86
UNI2	22	1.83	113.40
UNI3	19	1.80	95.26
UNI4	24	1.98	111.13
UNI5	21	1.88	102.06
UNI6	20	1.83	101.15
UNI7	22	1.70	81.65
UNI8	21	1.89	99.79
UNI9	21	1.84	88.45
UNI10	20	1.85	99.79
Mean UNI	21.30	1.85	100.15

Appendix F

Reliability Test Raw Data

Reliability Test Raw Data

Date	Stance width (m)	R heel from LOS (m)	R foot out-turn (°)	BS trunk flexion (°)	BS R shoulder flexion (°)	BS R elbow flexion (°)	BS hip flexion (°)	BS knee flexion (°)	release angle (°)	release velocity (m/s)
05-28-2009	1.14	0.86	26.60	12.40	131.40	9.90	161.70	84.90	16.40	16.46
06-5-2009	1.14	0.87	25.70	12.00	127.50	10.90	164.40	84.80	16.40	15.88
06-12-2009	1.13	0.86	26.90	12.10	129.20	9.70	157.80	83.70	16.00	15.49
06-19-2009	1.13	0.86	27.20	12.00	130.80	9.90	164.30	85.90	16.10	16.38
06-26-2009	1.14	0.87	27.10	11.80	128.10	10.80	161.30	86.00	16.90	15.92
Mean	1.14	0.86	26.70	12.06	129.40	10.24	161.90	85.06	16.36	16.03
SD	0.0055	0.0055	0.60	0.22	1.68	0.56	2.70	0.94	0.35	0.40
Minimum	1.13	0.86	25.70	11.80	128.10	9.70	157.80	83.70	16.00	15.49
Maximum	1.14	0.87	27.20	12.40	131.40	10.90	164.40	86.00	16.90	16.46
Range	0.010	0.010	1.50	0.60	3.30	1.20	6.60	2.30	0.90	0.97
Coefficient of Variance	0.0048	0.0063	0.023	0.018	0.013	0.055	0.017	0.011	0.021	0.025

Appendix G

High School Subjects' Raw Data

High School Subjects' Raw Data (Preliminary Movements)

Subject	Flexibility (0,1,2,3)	Stance width (m)	Stance width (percentage of standing height)	Right heel distance from LOS (m)	Left heel distance from LOS (m)	Distance from LOS (average of both feet) (m)	Right foot out-turn (° from sagittal)	Left foot out-turn (° from sagittal)
HS 1	1	0.83	43.46	0.81	0.76	0.79	45.40	39.70
HS 2	2	0.92	51.69	0.77	0.79	0.78	22.60	19.40
HS 3	3	1.07	60.11	0.62	0.68	0.65	24.70	33.20
HS 4	0	0.76	40.21	0.79	0.81	0.80	39.40	37.00
HS 5	3	1.14	61.96	0.86	0.87	0.87	26.60	27.70
HS 6	1	0.85	46.70	0.85	0.87	0.86	42.20	37.20
HS 7	3	0.86	47.78	0.90	0.88	0.89	42.90	40.60
HS 8	2	1.35	78.03	0.97	0.96	0.97	35.50	37.90
HS 9	2	1.06	63.10	0.86	0.78	0.82	47.20	40.30
HS 10	1	0.88	45.60	1.02	0.99	1.01	34.90	30.80
Mean	1.80	0.97	53.86	0.85	0.84	0.84	36.14	34.38
SD	1.03	0.18	11.69	0.11	0.094	0.101	8.87	6.77
SE	0.33	0.057	3.70	0.035	0.030	0.032	2.81	2.14

High School Subjects' Raw Data (Backswing)

Subject	BS Trunk flexion (° from horizontal)	BS Right shoulder flexion (°)	BS Left shoulder flexion (°)	BS Right elbow flexion (°)	BS Left elbow flexion (°)	BS Hip flexion (°)	BS Knee flexion (°)	BS Ankle dorsi-flexion (°)
HS 1	9.60	109.30	92.00	50.20	54.20	167.20	91.90	-5.60
HS 2	7.90	119.00	94.60	50.70	71.10	161.60	93.50	-12.40
HS 3	12.20	115.80	100.70	42.40	29.80	154.50	73.70	-11.20
HS 4	16.30	107.80	102.80	43.80	48.70	168.00	87.80	-9.80
HS 5	12.40	131.40	107.80	9.90	31.40	161.70	84.90	-9.90
HS 6	12.70	120.10	103.00	36.40	45.50	157.10	80.60	-8.90
HS 7	8.20	119.20	108.40	27.00	31.70	158.60	87.00	-7.80
HS 8	12.10	125.60	104.50	54.30	67.70	154.50	85.00	-12.20
HS 9	13.80	122.10	113.60	33.20	18.90	146.90	62.20	-8.60
HS 10	13.00	129.30	122.60	28.90	17.60	156.60	82.80	-11.80
Mean	11.82	119.96	105.00	37.68	41.66	158.67	82.94	-9.82
SD	2.58	7.71	8.87	13.53	18.88	6.30	9.20	2.17
SE	0.82	2.44	2.80	4.28	5.97	1.99	2.91	0.69

High School Subjects' Raw Data (Force Production)

Subject	Maximum right elbow flexion (MEF) (°)	Maximum left elbow flexion (MEF) (°)	Max. spinal flexion (spinous process to hip/shoulder line)(m)	FP Right shoulder extension ROM (°)	FP Right shoulder extension time (s)	FP Right shoulder extension velocity (°/sec)	FP Left shoulder extension ROM (°)	FP Left shoulder extension time (s)	FP Left shoulder extension velocity (°/sec)
HS 1	79.20	65.20	0.21	60.50	0.233	259.66	47.70	0.216	220.83
HS 2	70.40	67.30	0.16	73.20	0.200	366.00	54.00	0.200	270.00
HS 3	86.30	60.60	0.22	62.50	0.183	341.53	52.20	0.166	314.46
HS 4	71.80	55.70	0.22	61.50	0.216	284.72	54.70	0.216	253.24
HS 5	95.50	83.40	0.20	88.60	0.216	410.19	66.70	0.216	308.80
HS 6	55.10	42.50	0.18	63.40	0.200	317.00	51.00	0.183	278.69
HS 7	64.00	58.00	0.18	74.70	0.183	408.20	65.30	0.183	356.83
HS 8	107.50	88.00	0.20	91.50	0.233	392.70	64.20	0.216	297.22
HS 9	78.50	37.20	0.20	73.00	0.200	365.00	66.90	0.200	334.50
HS 10	73.00	65.70	0.23	74.30	0.200	371.50	80.80	0.200	404.00
Mean	78.13	62.36	0.20	72.32	0.206	351.65	60.35	0.200	303.86
SD	15.23	15.77	0.022	10.94	0.018	50.92	10.15	0.018	52.90
SE	4.82	4.99	0.0068	3.46	0.0056	16.10	3.21	0.0055	16.73

High School Subjects' Raw Data (Force Production continued)

Subject	FP Right elbow extension ROM (°)	FP Right elbow extension time (s)	FP Right elbow extension velocity (°/sec)	FP Left elbow extension ROM (°)	FP Left elbow extension time (s)	FP Left elbow extension velocity (°/sec)	FP Hip extension ROM (°)	FP Hip extension time (s)	FP Hip extension velocity (°/sec)
HS 1	73.10	0.116	630.17	57.60	0.100	576.00	4.60	0.233	19.74
HS 2	62.50	0.116	538.79	63.20	0.116	544.83	8.10	0.200	40.50
HS 3	76.20	0.083	918.07	52.20	0.083	628.92	4.60	0.183	25.14
HS 4	63.00	0.100	630.00	46.50	0.100	465.00	4.70	0.216	21.76
HS 5	83.60	0.083	1007.23	69.60	0.083	838.55	13.30	0.216	61.57
HS 6	44.10	0.100	441.00	30.30	0.100	303.00	10.70	0.200	53.50
HS 7	46.70	0.083	562.65	44.10	0.083	531.33	9.80	0.183	53.55
HS 8	81.20	0.100	812.00	35.70	0.100	357.00	12.50	0.233	53.65
HS 9	67.80	0.100	678.00	34.00	0.100	340.00	18.80	0.200	94.00
HS 10	52.60	0.083	633.73	32.90	0.083	396.39	8.80	0.200	44.00
Mean	65.08	0.096	685.17	46.61	0.095	498.10	9.59	0.206	46.74
SD	13.92	0.013	176.03	13.72	0.011	162.20	4.53	0.018	22.26
SE	4.40	0.0041	55.66	4.34	0.0036	51.29	1.43	0.0056	7.04

High School Subjects' Raw Data (Force Production continued)

Subject	FP Knee extension ROM (°)	FP Knee extension time (s)	FP Knee extension velocity (°/sec)	FP Ankle plantar-flexion ROM (°)	FP Ankle plantar-flexion time (s)	FP Ankle plantar-flexion velocity (°/sec)	FP Right shoulder medial rotation ROM (°)	FP Right shoulder medial rotation time (sec)	FP Right shoulder medial rotation velocity (°/sec)
HS 1	36.40	0.233	156.22	10.90	0.233	46.78	9.60	0.033	290.91
HS 2	47.60	0.200	238.00	18.40	0.200	92.00	2.30	0.033	69.70
HS 3	43.10	0.183	235.52	21.90	0.183	119.67	9.20	0.033	278.79
HS 4	34.10	0.216	157.87	13.00	0.216	60.19	11.80	0.033	357.58
HS 5	58.20	0.216	269.44	21.50	0.216	99.54	4.80	0.033	145.45
HS 6	51.20	0.200	256.00	32.10	0.200	160.50	6.90	0.033	209.09
HS 7	41.50	0.183	226.78	27.30	0.183	149.18	0.00	0.033	0.00
HS 8	51.60	0.233	221.46	21.10	0.233	90.56	0.00	0.033	0.00
HS 9	46.90	0.200	234.50	21.60	0.200	108.00	2.60	0.033	78.79
HS 10	37.50	0.200	187.50	20.60	0.200	103.00	6.10	0.033	184.85
Mean	44.81	0.206	218.33	20.84	0.206	102.94	5.33	0.033	161.52
SD	7.68	0.018	38.76	6.12	0.018	35.00	4.11	0.00	124.48
SE	2.43	0.0056	12.26	1.94	0.006	11.07	1.299	2E-18	39.36

High School Subjects' Raw Data (Force Production continued)

Subject	FP Left shoulder medial rotation ROM (°)	FP Left shoulder medial rotation time (sec)	FP Left shoulder medial rotation velocity (°/sec)	FP Right forearm pronation ROM (°)	FP Right forearm pronation time (sec)	FP Right forearm pronation velocity (°/sec)	FP Left forearm pronation ROM (°)	FP Left forearm pronation time (sec)	FP Left forearm pronation velocity (°/sec)	Release time (RT) (seconds)
HS 1	13.20	0.033	400.00	15.40	0.033	466.67	10.90	0.033	330.30	0.233
HS 2	0.00	0.033	0.00	13.00	0.033	393.94	11.10	0.033	336.36	0.200
HS 3	6.60	0.033	200.00	7.30	0.033	221.21	9.40	0.033	284.85	0.183
HS 4	15.30	0.033	463.64	14.60	0.033	442.42	13.20	0.033	400.00	0.216
HS 5	13.30	0.033	403.03	4.70	0.033	142.42	4.40	0.033	133.33	0.216
HS 6	5.30	0.033	160.61	6.90	0.033	209.09	7.60	0.033	230.30	0.200
HS 7	0.00	0.033	0.00	4.10	0.033	124.24	6.60	0.033	200.00	0.183
HS 8	0.00	0.033	0.00	16.10	0.033	487.88	7.70	0.033	233.33	0.233
HS 9	18.60	0.033	563.64	13.20	0.033	400.00	14.50	0.033	439.39	0.200
HS 10	0.00	0.033	0.00	7.90	0.033	239.39	7.20	0.033	218.18	0.200
Mean	7.23	0.033	219.09	10.32	0.033	312.73	9.26	0.033	280.61	0.206
SD	7.30	0.00	221.33	4.59	0.00	139.22	3.15	0.00	95.40	0.018
SE	2.31	2E-18	69.99	1.45	2E-18	44.02	1.00	2E-18	30.17	0.0056

High School Subjects' Raw Data (Critical Instant)

Subject	Total airborne time (seconds)	Right heel distance covered (m)	Left heel distance covered (m)	Total distance covered (average of both feet) (m)	Total flight time of ball (TFT) (seconds)	Total snap time (TST) (seconds)	Release height of ball (m)	Release height of ball (% of SH)	Release velocity of ball (m/s)
HS 1	0.150	0.24	0.24	0.24	1.134	1.367	0.18	0.094	12.72
HS 2	0.133	0.07	0.08	0.08	1.151	1.351	0.19	0.107	11.64
HS 3	0.183	0.18	0.27	0.23	1.067	1.250	0.16	0.090	13.00
HS 4	0.000	0.00	0.00	0.00	1.217	1.433	0.19	0.101	12.14
HS 5	0.216	0.23	0.25	0.24	0.784	1.000	0.14	0.076	16.46
HS 6	0.216	0.25	0.24	0.25	1.067	1.267	0.16	0.088	12.96
HS 7	0.200	0.23	0.26	0.25	0.884	1.067	0.16	0.089	14.72
HS 8	0.200	0.10	0.09	0.10	1.034	1.267	0.16	0.092	12.44
HS 9	0.200	0.09	0.09	0.09	1.051	1.251	0.15	0.089	12.50
HS 10	0.183	0.15	0.13	0.14	1.001	1.201	0.17	0.088	13.56
Mean	0.168	0.15	0.17	0.16	1.039	1.245	0.17	0.091	13.21
SD	0.065	0.086	0.097	0.091	0.127	0.132	0.016	0.0082	1.41
SE	0.021	0.027	0.031	0.029	0.040	0.042	0.005	0.0026	0.45

High School Subjects' Raw Data (Critical Instant continued)

Subject	Release angle of ball (° from horizontal)	Average linear velocity of ball (m/s)	Average angular velocity of ball (°/sec)	Angular momentum of ball (kg•m2/sec)	CI Forward trunk lean (° from horizontal)	CI Right shoulder flexion (°)	CI Left shoulder flexion (°)	CI Right elbow flexion (°)	CI Left elbow flexion (°)
HS 1	29.30	11.29	2094.90	0.078	29.90	48.80	44.30	6.10	7.60
HS 2	31.40	11.12	2658.56	0.099	27.70	45.80	40.60	7.90	4.10
HS 3	20.80	12.00	2361.76	0.088	31.40	53.30	48.50	10.10	8.40
HS 4	29.90	10.52	1848.81	0.069	34.80	46.30	48.10	8.80	9.20
HS 5	16.40	16.33	3000.00	0.112	32.40	42.80	41.10	11.90	13.80
HS 6	22.70	12.00	2055.19	0.077	27.60	56.70	52.00	11.00	12.20
HS 7	18.80	14.48	2329.41	0.087	21.70	44.50	43.10	17.30	13.90
HS 8	22.80	12.38	1858.41	0.069	24.10	34.10	40.30	26.30	52.30
HS 9	27.30	12.18	2611.22	0.097	27.20	49.10	46.70	10.70	3.20
HS 10	19.40	12.79	2195.12	0.082	24.90	55.00	41.80	20.40	32.80
Mean	23.88	12.51	2301.34	0.086	28.17	47.64	44.65	13.05	15.75
SD	5.25	1.72	369.93	0.014	4.03	6.61	3.99	6.33	15.29
SE	1.66	0.54	116.98	0.0044	1.27	2.09	1.26	2.00	4.83

High School Subjects' Raw Data (Critical Instant continued)

Subject	CI Right shoulder medial rotation from arm/leg contact (°)	CI Left shoulder medial rotation from arm/leg contact (°)	CI Right forearm pronation from arm/leg contact (°)	CI Left forearm pronation from arm/leg contact (°)	CI Hip flexion (°)	CI Knee flexion (°)	CI Ankle plantar-flexion (°)
HS 1	9.60	13.20	15.40	10.90	162.60	55.50	5.30
HS 2	2.30	0.00	13.00	11.10	153.50	45.90	6.00
HS 3	9.20	6.60	7.30	9.40	149.90	30.60	10.70
HS 4	11.80	15.30	14.60	13.20	163.30	53.70	3.20
HS 5	4.80	13.30	4.70	4.40	148.40	26.70	11.60
HS 6	6.90	5.30	6.90	7.60	146.40	29.40	23.20
HS 7	0.00	0.00	4.10	6.60	148.80	45.50	19.50
HS 8	0.00	0.00	16.10	7.70	142.00	33.40	8.90
HS 9	2.60	18.60	13.20	14.50	128.10	15.30	13.00
HS 10	6.10	0.00	7.90	7.20	147.80	45.30	8.80
Mean	5.33	7.23	10.32	9.26	149.08	38.13	11.02
SD	4.11	7.30	4.59	3.15	10.03	12.98	6.26
SE	1.30	2.31	1.45	1.00	3.17	4.11	1.98

High School Subjects' Raw Data (Follow Through)

Subject	FT Forward trunk lean (° from horizontal)	FT Right shoulder flexion (°)	FT Left shoulder flexion (°)	FT Hip Flexion (°)	FT Knee flexion (°)
HS 1	38.30	28.50	34.80	168.00	45.40
HS 2	31.20	29.40	30.00	158.10	43.50
HS 3	30.60	35.90	40.50	145.20	37.90
HS 4	43.20	35.60	36.90	165.10	48.90
HS 5	40.10	32.10	30.60	155.70	32.60
HS 6	31.90	32.80	39.40	145.10	30.90
HS 7	25.60	29.50	36.10	151.60	46.20
HS 8	25.80	28.20	40.90	138.90	31.90
HS 9	31.30	42.40	42.90	130.70	16.00
HS 10	32.10	37.30	27.40	153.60	54.10
Mean	33.01	33.17	35.95	151.20	38.74
SD	5.80	4.61	5.22	11.52	11.18
SE	1.83	1.46	1.65	3.64	3.54

Appendix H

University Subjects' Raw Data

University Subjects' Raw Data (Preliminary Movements)

Subject	Flexibility (0,1,2,3)	Stance width (m)	Stance width (percentage of standing height)	Right heel distance from LOS (m)	Left heel distance from LOS (m)	Distance from LOS (average of both feet) (m)	Right foot out-turn (° from sagittal)	Left foot out-turn (° from sagittal)
UNI1	2	1.10	56.99	0.89	0.91	0.90	21.90	33.40
UNI2	1	1.14	62.3	0.88	0.86	0.87	35.90	38.10
UNI3	3	1.16	64.44	0.92	0.91	0.92	33.20	20.30
UNI4	3	1.23	62.12	0.75	0.80	0.78	41.90	40.20
UNI5	3	0.92	48.94	0.89	0.88	0.89	34.50	33.00
UNI6	2	0.93	50.82	0.68	0.70	0.69	45.20	40.70
UNI7	3	1.21	71.18	0.99	1.01	1.00	48.50	38.80
UNI8	3	0.94	49.74	0.74	0.71	0.73	38.50	37.00
UNI9	2	1.14	61.96	0.92	0.90	0.91	38.40	30.90
UNI10	3	1.00	54.05	0.86	0.87	0.87	37.60	34.40
Mean	2.50	1.077	58.25	0.85	0.86	0.85	37.56	34.68
SD	0.71	0.12	7.33	0.10	0.095	0.095	7.26	6.02
SE	0.22	0.038	2.32	0.031	0.030	0.030	2.30	1.90

University Subjects' Raw Data (Backswing)

Subject	BS Trunk flexion (° from horizontal)	BS Right shoulder flexion (°)	BS Left shoulder flexion (°)	BS Right elbow flexion (°)	BS Left elbow flexion (°)	BS Hip flexion (°)	BS Knee flexion (°)	BS Ankle dorsi-flexion (°)
UNI1	14.00	127.60	123.70	24.60	16.90	162.30	75.90	-9.60
UNI2	18.60	127.90	118.20	46.50	44.70	156.10	67.20	-8.00
UNI3	12.20	123.50	118.50	42.70	47.90	163.00	85.70	-10.90
UNI4	8.50	105.90	99.90	40.70	29.50	154.30	79.80	-9.10
UNI5	10.60	119.80	100.00	34.70	46.10	168.80	94.00	-10.40
UNI6	2.80	102.80	87.80	38.90	52.60	163.60	95.90	-8.10
UNI7	20.10	139.20	130.10	26.20	32.80	145.40	41.90	-5.20
UNI8	6.40	104.50	90.10	41.50	46.80	169.30	96.10	-9.80
UNI9	22.40	141.50	116.50	19.50	54.90	163.60	71.50	-4.50
UNI10	-8.10	98.70	90.60	34.60	35.60	152.90	99.50	-9.30
Mean	10.75	119.14	107.54	34.99	40.78	159.93	80.75	-8.49
SD	9.07	15.44	15.56	8.87	11.82	7.57	17.70	2.12
SE	2.87	4.88	4.92	2.80	3.74	2.39	5.60	0.67

University Subjects' Raw Data (Force Production)

Subject	Maximum right elbow flexion (MEF) (°)	Maximum left elbow flexion (MEF) (°)	Max. spinal flexion (spinous process to hip/shoulder line)(m)	FP Right shoulder extension ROM (°)	FP Right shoulder extension time (s)	FP Right shoulder extension velocity (°/sec)	FP Left shoulder extension ROM (°)	FP Left shoulder extension time (s)	FP Left shoulder extension velocity (°/sec)
UNI1	100.20	85.50	0.19	60.90	0.250	243.60	60.70	0.233	260.52
UNI2	88.50	77.20	0.25	73.90	0.216	342.13	60.00	0.200	300.00
UNI3	80.20	71.50	0.21	77.60	0.216	359.26	71.60	0.216	331.48
UNI4	86.40	71.30	0.23	51.90	0.283	183.39	46.00	0.283	162.54
UNI5	83.60	73.10	0.22	75.90	0.200	379.50	54.20	0.200	271.00
UNI6	86.40	78.00	0.19	38.50	0.183	210.38	32.60	0.183	178.14
UNI7	100.30	94.20	0.17	93.30	0.216	431.94	84.40	0.216	390.74
UNI8	79.90	73.40	0.24	59.90	0.200	299.50	49.20	0.200	246.00
UNI9	77.70	76.80	0.19	98.80	0.200	494.00	64.10	0.200	320.50
UNI10	104.10	101.30	0.22	51.90	0.216	240.28	42.70	0.216	197.69
Mean	88.73	80.23	0.21	68.26	0.218	318.40	56.55	0.215	265.86
SD	9.49	10.25	0.026	19.10	0.029	100.91	15.00	0.028	72.66
SE	3.00	3.24	0.0081	6.04	0.0091	31.91	4.74	0.0087	22.98

University Subjects' Raw Data (Force Production continued)

Subject	FP Right elbow extension ROM (°)	FP Right elbow extension time (s)	FP Right elbow extension velocity (°/sec)	FP Left elbow extension ROM (°)	FP Left elbow extension time (s)	FP Left elbow extension velocity (°/sec)	FP Hip extension ROM (°)	FP Hip extension time (s)	FP Hip extension velocity (°/sec)
UNI1	88.90	0.100	889.00	63.10	0.100	631.00	26.00	0.250	104.00
UNI2	75.20	0.100	752.00	67.30	0.083	810.84	13.40	0.216	62.04
UNI3	66.60	0.100	666.00	67.00	0.100	670.00	13.40	0.216	62.04
UNI4	66.00	0.083	795.18	56.10	0.083	675.90	-3.40	0.283	-12.01
UNI5	68.20	0.100	682.00	66.30	0.100	663.00	6.90	0.200	34.50
UNI6	73.20	0.100	732.00	61.90	0.100	619.00	10.50	0.183	57.38
UNI7	80.70	0.083	972.29	82.90	0.083	998.80	9.70	0.216	44.91
UNI8	66.00	0.100	660.00	66.10	0.100	661.00	5.50	0.200	27.50
UNI9	63.40	0.083	763.86	63.70	0.083	767.47	10.60	0.200	53.00
UNI10	88.20	0.083	1062.65	84.90	0.083	1022.89	-4.70	0.216	-21.76
Mean	73.64	0.093	797.50	67.93	0.092	751.99	8.79	0.218	41.16
SD	9.42	0.0088	135.92	9.05	0.0090	148.71	8.76	0.029	36.90
SE	2.98	0.0028	42.98	2.86	0.0028	47.03	2.77	0.0091	11.67

University Subjects' Raw Data (Force Production continued)

Subject	FP Knee extension ROM (°)	FP Knee extension time (s)	FP Knee extension velocity (°/sec)	FP Ankle plantar-flexion ROM (°)	FP Ankle plantar-flexion time (s)	FP Ankle plantar-flexion velocity (°/sec)	FP Right shoulder medial rotation ROM (°)	FP Right shoulder medial rotation time (sec)	FP Right shoulder medial rotation velocity (°/sec)
UNI1	71.20	0.250	284.80	25.30	0.250	101.20	6.20	0.033	187.88
UNI2	38.80	0.216	179.63	18.50	0.216	85.65	12.10	0.033	366.67
UNI3	55.10	0.216	255.09	19.90	0.216	92.13	15.40	0.050	308.00
UNI4	23.90	0.283	84.45	9.80	0.283	34.63	4.80	0.033	145.45
UNI5	33.30	0.200	166.50	15.20	0.200	76.00	11.00	0.033	333.33
UNI6	61.90	0.183	338.25	18.40	0.183	100.55	7.70	0.050	154.00
UNI7	21.60	0.216	100.00	16.30	0.216	75.46	7.40	0.033	224.24
UNI8	38.60	0.200	193.00	16.00	0.200	80.00	7.90	0.050	158.00
UNI9	33.90	0.200	169.50	13.70	0.200	68.50	1.80	0.033	54.55
UNI10	62.60	0.216	289.81	18.80	0.216	87.04	3.20	0.050	64.00
Mean	44.09	0.218	206.10	17.19	0.218	80.12	7.75	0.040	199.61
SD	17.35	0.029	83.60	4.11	0.029	19.23	4.15	0.0088	107.73
SE	5.49	0.0091	26.44	1.30	0.0091	6.08	1.31	0.0028	34.07

University Subjects' Raw Data (Force Production continued)

Subject	FP Left shoulder medial rotation ROM (°)	FP Left shoulder medial rotation time (sec)	FP Left shoulder medial rotation velocity (°/sec)	FP Right forearm pronation ROM (°)	FP Right forearm pronation time (sec)	FP Right forearm pronation velocity (°/sec)	FP Left forearm pronation ROM (°)	FP Left forearm pronation time (sec)	FP Left forearm pronation velocity (°/sec)	Release time (RT) (seconds)
UNI1	7.80	0.033	236.36	11.60	0.033	351.52	12.70	0.033	384.85	0.233
UNI2	14.30	0.033	433.33	7.30	0.033	221.21	6.80	0.033	206.06	0.216
UNI3	13.40	0.050	268.00	6.80	0.033	206.06	10.70	0.050	214.00	0.216
UNI4	4.80	0.033	145.45	6.60	0.033	200.00	9.00	0.033	272.73	0.266
UNI5	7.70	0.033	233.33	7.20	0.033	218.18	6.80	0.033	206.06	0.200
UNI6	7.80	0.050	156.00	8.00	0.050	160.00	7.60	0.050	152.00	0.183
UNI7	5.20	0.033	157.58	5.90	0.033	178.79	6.90	0.033	209.09	0.216
UNI8	6.00	0.050	120.00	7.90	0.050	158.00	3.50	0.050	70.00	0.200
UNI9	2.80	0.033	84.85	6.30	0.033	190.91	4.10	0.033	124.24	0.200
UNI10	3.90	0.050	78.00	11.40	0.050	228.00	6.10	0.050	122.00	0.216
Mean	7.37	0.040	191.29	7.90	0.038	211.27	7.42	0.040	196.10	0.215
SD	3.81	0.0088	106.46	2.01	0.0082	54.96	2.80	0.0088	88.62	0.023
SE	1.21	0.0028	33.66	0.63	0.0026	17.38	0.88	0.0028	28.02	0.0072

University Subjects' Raw Data (Critical Instant)

Subject	Total airborne time (seconds)	Right heel distance covered (m)	Left heel distance covered (m)	Total distance covered (average of both feet) (m)	Total flight time of ball (TFT) (seconds)	Total snap time (TST) (seconds)	Release height of ball (m)	Release height of ball (% of SH)	Release velocity of ball (m/s)
UNI1	0.183	0.30	0.30	0.30	0.800	1.033	0.13	0.067	16.11
UNI2	0.200	0.19	0.17	0.18	0.900	1.116	0.12	0.066	14.44
UNI3	0.216	0.37	0.38	0.38	0.967	1.183	0.16	0.089	13.89
UNI4	0.150	0.18	0.19	0.19	0.917	1.183	0.15	0.076	14.09
UNI5	0.216	0.29	0.31	0.30	0.834	1.034	0.09	0.048	15.68
UNI6	0.233	0.37	0.38	0.38	0.850	1.033	0.16	0.087	15.11
UNI7	0.216	0.30	0.25	0.28	0.817	1.033	0.13	0.076	15.84
UNI8	0.216	0.30	0.30	0.30	0.900	1.100	0.11	0.058	15.27
UNI9	0.216	0.24	0.23	0.24	0.884	1.084	0.12	0.065	15.07
UNI10	0.233	0.44	0.41	0.43	0.834	1.050	0.12	0.065	16.02
Mean	0.208	0.30	0.29	0.30	0.870	1.085	0.13	0.070	15.15
SD	0.025	0.081	0.082	0.081	0.052	0.060	0.0223	0.013	0.79
SE	0.0079	0.026	0.026	0.026	0.016	0.019	0.0071	0.0040	0.25

University Subjects’ Raw Data (Critical Instant continued)

Subject	Release angle of ball (° from horizontal)	Average linear velocity of ball (m/s)	Average angular velocity of ball (°/sec)	Angular momentum of ball (kg•m2/sec)	CI Forward trunk lean (° from horizontal)	CI Right shoulder flexion (°)	CI Left shoulder flexion (°)	CI Right elbow flexion (°)	CI Left elbow flexion (°)
UNI1	17.20	16.00	2581.49	0.096	35.90	66.70	63.00	11.30	22.40
UNI2	18.10	14.22	2036.20	0.076	24.30	54.00	58.20	13.30	9.90
UNI3	22.20	13.24	2233.71	0.083	26.90	45.90	46.90	13.60	4.50
UNI4	23.00	13.96	2541.18	0.095	35.20	54.00	53.90	20.40	15.20
UNI5	15.90	15.35	2864.14	0.107	22.70	43.90	45.80	15.40	6.80
UNI6	18.10	15.06	2482.01	0.093	35.80	64.30	55.20	13.20	16.10
UNI7	19.30	15.67	2643.82	0.099	24.60	45.90	45.70	19.60	11.30
UNI8	20.10	14.22	2557.89	0.095	25.00	44.60	40.90	13.90	7.30
UNI9	20.40	14.48	2443.44	0.091	33.80	42.70	52.40	14.30	13.10
UNI10	18.30	15.35	2805.76	0.105	30.70	46.80	47.90	15.90	16.40
Mean	19.26	14.75	2518.96	0.094	29.49	50.88	50.99	15.09	12.30
SD	2.21	0.87	245.95	0.0092	5.35	8.64	6.73	2.88	5.43
SE	0.70	0.27	77.78	0.0029	1.69	2.73	2.13	0.91	1.72

University Subjects' Raw Data (Critical Instant continued)

Subject	CI Right shoulder medial rotation from arm/leg contact (°)	CI Left shoulder medial rotation from arm/leg contact (°)	CI Right forearm pronation from arm/leg contact (°)	CI Left forearm pronation from arm/leg contact (°)	CI Hip flexion (°)	CI Knee flexion (°)	CI Ankle plantar-flexion (°)
UNI1	6.20	7.80	11.60	12.70	136.30	4.70	15.70
UNI2	12.10	14.30	7.30	6.80	142.70	28.40	10.50
UNI3	15.40	13.40	6.80	10.70	149.60	30.60	9.00
UNI4	4.80	4.80	6.60	9.00	157.70	55.90	0.70
UNI5	11.00	7.70	7.20	6.80	161.90	60.70	4.80
UNI6	7.70	7.80	8.00	7.60	153.10	34.00	10.30
UNI7	7.40	5.20	5.50	6.90	135.70	20.30	11.10
UNI8	7.90	6.00	5.20	3.50	163.80	57.50	6.20
UNI9	1.80	2.80	6.30	4.10	153.00	37.60	9.20
UNI10	3.20	3.90	11.40	6.10	157.60	36.90	9.50
Mean	7.75	7.37	7.59	7.42	151.14	36.66	8.70
SD	4.15	3.81	2.22	2.80	10.00	17.59	4.04
SE	1.31	1.21	0.70	0.88	3.16	5.56	1.28

University Subjects' Raw Data (Follow Through)

Subject	FT Forward trunk lean (° from horizontal)	FT Right shoulder flexion (°)	FT Left shoulder flexion (°)	FT Hip Flexion (°)	FT Knee flexion (°)
UNI1	37.50	56.60	47.50	129.10	2.10
UNI2	25.50	39.10	38.40	152.50	45.90
UNI3	30.00	35.60	41.30	149.50	29.30
UNI4	43.50	38.30	32.60	161.70	48.90
UNI5	35.60	32.40	40.70	162.10	36.40
UNI6	38.30	39.10	41.80	152.80	38.30
UNI7	26.60	34.50	37.40	138.60	21.10
UNI8	32.30	34.10	39.20	161.50	39.60
UNI9	39.80	27.00	31.40	161.40	49.70
UNI10	33.60	36.40	37.00	162.40	53.70
Mean	34.27	37.31	38.73	153.16	36.50
SD	5.80	7.69	4.63	11.45	15.63
SE	1.83	2.43	1.47	3.62	4.94

Additional Notes