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A COMPLETE KINEMATIC, KINETIC, AND ELECTROMYOGRAPHICAL ANALYSIS OF THE FOOTBALL THROW IN COLLEGIATE QUARTERBACKS

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A COMPLETE KINEMATIC, KINETIC, AND ELECTROMYOGRAPHICAL ANALYSIS OF THE FOOTBALL THROW IN COLLEGIATE QUARTERBACKS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Education at the University of Kentucky

By

Kyle Bohnert

Lexington, Kentucky

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2016

ABSTRACT OF THESIS

A COMPLETE KINEMATIC, KINETIC, AND ELECTROMYOGRAPHICAL ANALYSIS OF THE FOOTBALL THROW IN COLLEGIATE QUARTERBACKS

The biomechanics of the overhead throw has been extensively studied in regards to baseball pitching. However, an understanding of the proper mechanics needed to successfully throw a football has not previously been investigated. Thus, the purpose of this study was to investigate the kinematics, kinetics, and electromyography of the football throws in elite quarterbacks. Three collegiate quarterbacks were evaluated using a multi-camera motion capture system and electromyography electrodes. The results of this study are able to give a breakdown in the types of mechanics needed in each of the phases of the throw. This study demonstrated that during the early cocking phase, most of the movement seen in the upper body occurs in the frontal plane to abduct the shoulder. During the late cocking phase, the shoulder holds a constant abduction angle and begins to externally rotate. The shoulder reaches a value of 117° of external rotation, much less than has previously been reported. During the acceleration phase, the shoulder rapidly internally rotates as well as horizontally adducts. Once the ball is released, the shoulder has to produce large forces and muscle activity to slow down the rotation. These results will be able to give coaches and players a tool for what to look for when evaluating the mechanics of an individual.

KEYOWRDS: Biomechanics, Quarterback, Throwing, Electromyography, Kinematics

Kyle Bohnert
6-27-16

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CHAPTER ONE

Introduction

Proper mechanics of throwing a football are essential for quarterbacks of all levels of play to be successful as well as stay healthy. Therefore, a complete kinematic study is needed in order for coaches and players alike to understand proper throwing mechanics.

There are only two known articles investigating the mechanics specifically involved in the football throw. Fleisig et al compared the kinematic and kinetic parameters of baseball pitching to that of throwing a football (C. S. Fleisig, Escamilla, Andrews, Matsuo, & Barrentine, 1996). In addition to this study, Rash & Shapiro examined the dynamics of the shoulder and elbow joints during throws by 12 quarterbacks at the Senior Bowls from 1990-1992 (Rash & Shapiro, 1995). In a similar manner, only one known study has examined the muscle activity of any muscle during the football throw. Kelly et al examined the muscle activity and recruitment pattern of the football throw of nine muscles in the throwing arm throughout five stages of the throw (Kelly, Backus, Warren, & Williams, 2002). However, the implementation of kinematic, kinetic, and electromyography variable into one study has been done.

Although there has been a lack of research in the study of the football throw, the throwing motion during the football throw is similar to that of the baseball pitch, which has been considerably more studied. However, the study mentioned above by Fleisig demonstrated that there exist differences between these two motions (Fleisig, Escamilla et al. 1996). Thus, extensive knowledge of baseball alone is not enough to fully understand the football throw. This raises the need for specific studies of the football motion.

The literature present for both the football and baseball throw present a general knowledge of the mechanics involved in the football throw. However, a specific study incorporating all aspects of the throw to give a complete picture of the mechanics is still needed.

Problem

Although there has been extensive research in the area of overhead throwing, there has been only one article that provides a thorough descriptive analysis of the kinematics and kinetics of a football throw. In this same manner, only one such article exists providing a descriptive analysis of muscle activity of the throw. This study, however, was limited in that only intramural athletes served as subjects for the study as well as only upper extremity muscles were examined.

No study has combined both kinematic and kinetic aspects of the throw to determine how they relate to the activity that is occurring in the muscles. Therefore, there is very little knowledge pertaining to the complete mechanics of the throw. This lack of knowledge could be limiting our ability to properly teach the mechanics and assess the pathomechanics associated with injury.

Purpose

The primary purpose of this study was to conduct an extensive descriptive study of the football throw in elite collegiate quarterbacks. This descriptive study would incorporate data from kinematics, kinetics, and muscular activity.

Significance

This study will help to provide insight into the mechanics of the football throw of the collegiate quarterback. These results could become useful for ability of coaches to properly teach the mechanics. In addition, this research could allow for the proper diagnosis of pathomechanics in quarterbacks and their successive training programs.

Delimitations

This study was done with a group of college quarterbacks at The University of Kentucky. The group consisted of 3 college-aged student athletes. Each data collection consisted of ten throws of appropriate effort to execute a pass of approximately 30 yards distance. Kinematic data were collected using a Motion Analysis (Motion Analysis Corp., Santa Rosa, CA) motion capture system. Ground reaction forces were collected using two Bertec (Bertec Corp, Columbus, OH) force platforms. Lastly, electromyography was collected using a 16 lead Delsys (Delsys, Boston, MA) EMG system. Each data collection session lasted approximately one hour.

Limitations

There were several limitations to the study. The first major limitation to the study was the number of participants. However, all available collegiate quarterbacks at the university partook in the study. Another important limitations was the inability to control for each subjects training load. One subject in the study was a starter for the football team, while the other two were red shirted for the year. Another limitation to the study could be due to the execution of the manual muscle exams. The exams were completed to the best of the tester's ability. However, in some instances, the strength of the participant might have been greater than the tester's ability to resist. Thus, an inaccurate maximal contraction could have occurred. One last limitation was the setting in which the data was collected. The subjects threw footballs with numerous markers on their skin as well as electrodes with wires that could have impeded their motion. Lastly, they were throwing inside a lab with a net. This setting does not simulate what they experience during a game.

CHAPTER TWO

Literature Review

The purpose of this study was to provide a comprehensive analysis of the collegiate football throw in regards to kinematics, kinetics, and electromyography. For this study, three collegiate quarterbacks completed several testing sessions. However, for the purpose of the current report, only the initial session was analyzed.

The purpose of this chapter will be to provide background for the variables that will be examined in this study. In order to do this, research from the most studied overhead throwing motion, baseball, will be combined with the current knowledge already known from the football throw.

Background

Football Throwing

The kinematics, kinetics, and electromyography of the football throw are examined in this section. This section will also discuss prevalent injuries seen in quarterbacks.

Kinematics

For this review we will split the phases of the throw into six phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow through as previously reported in the literature (C. S. Fleisig et al., 1996). However, the study done by Rash and Shapiro only examined variables at foot contact, maximum external rotation, and release. These variables will be discussed with the phases stated by Fleisig et al in which they most pertain. Figure 1 below shows the phases of the throws of a football player as described by Fleisig.

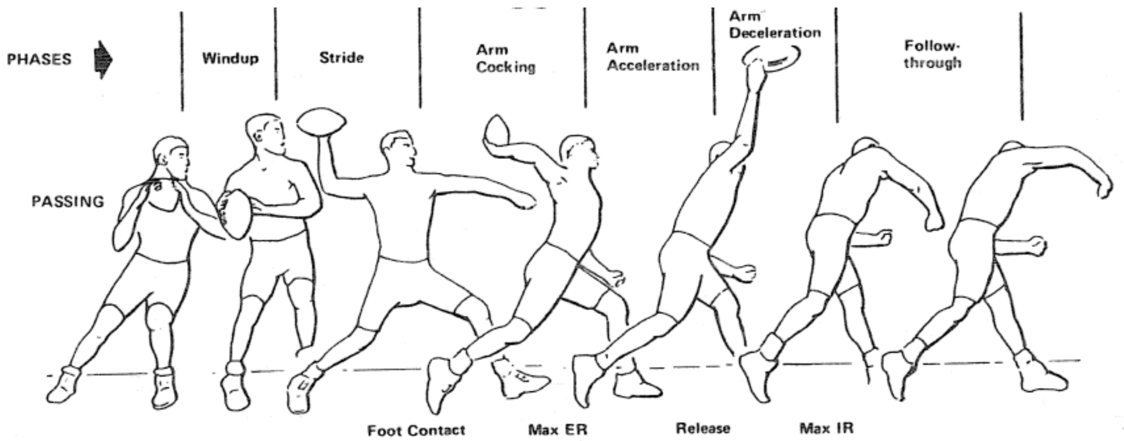


FIGURE 1: A depiction of the phases of the throw as shown by Fleisig et al. (C. S. Fleisig et al., 1996)

There have only been two known articles to examine kinematic variables associated with the football throw. Before beginning in a discussion of the finding from these papers, a general overview of the results is shown below in Table 1.

	Fleisig et al 1996	Rash & Shapiro 1995
Instant of Foot Contact		
Stride length ankle-ankle (%Height)	61	-
Shoulder Abduction (°)	96	97
Shoulder Horizontal Adduction (°)	7	-1
Shoulder External Rotation (°)	90	47
Elbow Flexion (°)	77	75
Lead Knee Flexion (°)	39	-
Arm Cocking Phase		-
Max Pelvis Angular Velocity (°/s)	500	-
Max Shoulder Horizontal Adduction (°)	32	-
Max Upper Torso Angular Velocity (°/s)	950	-
Max Elbow Flexion (°)	113	-
Instant of Maximum Should Ex Rotation		
Max Should External Rotation (°)	164	164
Arm Acceleration Phase		
Max Elbow Extension Velocity (°/s)	1760	-
Instant Ball Release		
Ball Velocity (m/s)	21	-
Should Horizontal Adduction (°)	26	12
Elbow Flexion (°)	36	121
Trunk Tilt Forward (°)	65	-
Trunk Tilt Side (°)	116	-
Lead Knee Flexion (°)	28	-
Arm Deceleration Phase		
Max Should Internal Rotation Velocity (°/s)	4950	2987
Min Elbow Flexion (°)	24	-

TABLE 1: Kinematic results throughout each phase as seen in quarterbacks (C. S. Fleisig et al., 1996; Rash & Shapiro, 1995)

In both articles, the windup phase was omitted, as the typical football throw does not have a windup phase. Both articles initiated their analyses on variables starting with rear foot contact as the thrower stepped back to prepare for the throw. At rear foot contact the shoulder is both abducted and horizontally abducted. In addition, the shoulder was externally rotating while the forearm remained flexed at the elbow (Rash & Shapiro, 1995). Fleisig et al defined shoulder abduction, horizontal adduction, shoulder external rotation, and elbow flexion at this instance as 96°, 7°, 90°, and 77° respectively. The lead knee flexion angle was also defined as 39° of flexion (C. S. Fleisig et al., 1996).

During the cocking phase the quarterbacks exhibited a small horizontal adduction velocity (Rash & Shapiro, 1995). The maximum velocity demonstrated in this phases is 32 °/s. Similarly, during this phase the elbow exhibited a minimal trend towards an elbow flexion velocity (Rash & Shapiro, 1995). The maximum elbow flexion angle has been demonstrated to be 113°. In addition to these values, the maximum angular velocity about the z-axis of the pelvis and torso was found to be 500°/s and 950°/s respectively (C. S. Fleisig et al., 1996). This rotation was toward the target, allowing the front of the torso to be facing the target.

The instant of maximum external rotation is the event that marks the end of the cocking phase and the beginning of the acceleration phase. In the two articles, the amount of maximum external rotation has been determined to be 166° and 164° (C. S. Fleisig et al., 1996; Rash & Shapiro, 1995). This instant occurred at approximately 71% of the throw in each article. During the arm acceleration phase, the elbow begins to exhibit an extension velocity at the elbow. The maximum angular elbow extension velocity has been reported as 1,760°/s (C. S. Fleisig et al., 1996). As seen in the data reported by Rash and Shapiro, the shoulder begins internal rotation before the elbow begins to extend. This would indicate a kinetic chain of motion with the more proximal joint moving first. As will be discussed later on, this kinetic chain differs from that of the baseball throw and tennis serve.

The instant of ball release signifies the transition to the deceleration phase. Ball release is most generally considered to be 100% of the throw. At ball release there is a trend towards horizontal adduction (Rash & Shapiro, 1995). This value was later quantified to be 26°. Also at this instance, elbow flexion and lead knee flexion were determined to be 36° and 28° respectively (C. S. Fleisig et al., 1996).

During the deceleration phase, a large internal rotation velocity was exhibited in all quarterbacks(Rash & Shapiro, 1995). The maximum value of this has been reported as 4,950°/s and has been stated as occurring at 106% of the throw (C. S. Fleisig et al., 1996). This maximum velocity occurs immediately after ball release as the weight of the ball has been removed. Throughout the remainder of the throw, the internal rotation velocity will start to decrease. In addition the elbow continues to extend in the quarterbacks, but at a slower velocity. The minimum elbow flexion angle caused by this velocity has been determined to be 24° and occur at approximately 107% of the throw (C. S. Fleisig et al., 1996).

The maximum ball velocity reported by both these studies was slightly different. Fleisig et al reported a maximum velocity of 22 m/s while Rash and Shapiro reported a ball velocity of only 18.2 m/s. Both papers used a radar gun to calculate ball velocity. These results taken together demonstrate similarities seen across two different studies on quarterbacks. However, Fleisig et al studied additional variable not included in Rash and Shapiro's report. Thus, there is still need for additional studies of these variables in quarterbacks.

Kinetics

As seen with the kinematics, the same two articles are the only known articles to explore the kinetics of the football throw (C. S. Fleisig et al., 1996; Rash & Shapiro, 1995). The current section on kinetics will follow the same outline as the previous section in reviewing the variables at each phase in the football throw.

During the arm cocking phase, forces and toques at the shoulder and elbow were observed. The maximum shoulder anterior force was determined to be 350N, while the maximum horizontal adduction and internal rotation torques were calculated to be 78Nm and 54Nm. The maximum elbow medial force was determined to be 280N with a maximum elbow varus torque of 54Nm. This amount of anterior force in the shoulder is important when looking for injuries to the anterior glenoid labrum. These injuries can occur if the humerus gets shifted to the rim of the glenoid fossa. However, this injury occurs less frequently in quarterbacks as compared to pitchers. The value of anterior force in quarterbacks was determined to be similar to pitchers. The authors hypothesized that the additional horizontal adduction in quarterbacks aids in the joints stability (C. S. Fleisig et al., 1996).

During the arm acceleration phase, quarterbacks exhibited a maximum elbow flexion torque of 41Nm (F). This value was not specified as to when in the phase it occurred. During the acceleration phase, the elbow is undergoing a rapid extension. Thus, the elbow is producing a flexion torque to try to stabilize the joint. In addition, the elbow must produce a varus torque in order to maintain joint stability and prevent injuries seen in the elbow. Elbow varus torque was determined to be 54Nm, comparable to that seen in the pitchers of the Fleisig study (C. S. Fleisig et al., 1996). Thus, the authors were not able to hypothesize as to the decrease in elbow injuries seen in football.

The maximum compressive force of the shoulder and the elbow during the arm deceleration phase was determined to be 660N and 620N respectively. These two forces are used to resist the distraction that is occurring at these two joints. The compression force in the shoulder was determined to be less that baseball, potentially demonstrating the decrease risk of injury in quarterbacks. A maximum shoulder adduction torque of 58Nm was also observed at this phase. The follow through phase exhibited a maximum shoulder posterior force 240N. In addition the maximum shoulder horizontal abduction torque was determined to be 80Nm.

As seen in these data, there is a sequential timing of peak torques seen in the throwing motion. As discussed in Rash and Shapiro, the sequence goes from peak abduction torque, to peak internal rotation torque, to lastly peak horizontal adduction torque right before ball release (Rash & Shapiro, 1995).

Electromyography

As mentioned in Chapter One, there is only one known article examining the muscular activity of the American football throw. Nine muscles were studied on 14 male recreational athletes. The muscles examined by this study were the supraspinatus, infraspinatus, subscapularis, anterior deltoid, middle deltoid, posterior deltoid, pectoralis major, latissimus dorsi, and biceps brachii. In this study, Kelly separated the throw into four phases. The first phase, early cocking, occurred from rear foot plant to maximum shoulder abduction and internal rotation. The second phase, late cocking, occurred from maximum shoulder abduction and internal rotation to maximum shoulder external rotation. The third phase, arm acceleration, occurred from maximum shoulder external rotation to ball release. The fourth and final stage, arm deceleration and follow through, occurred from ball release to maximum shoulder horizontal adduction. A general table of the results seen in this study is provided in Table 2 (Kelly et al., 2002).

Muscle	**Early Cocking**		**Late Cocking**		**Acceleration**		**Follow Throug**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
R Biceps Brachii	12	7	12	10	11	9	20	18
R Anterior Deltoid	13	9	40	14	49	14	43	26
R Posterior Deltoid	11	6	11	15	32	22	53	25
R Latissimus Dorsi	7	3	18	9	65	30	72	42
R Middle Deltoid	21	12	14	14	24	14	48	19
R Pectoralis Major	12	14	51	38	86	33	79	54
R Supraspinatus	45	19	62	20	65	30	87	43
R Infraspinatus	46	17	67	19	69	29	86	33
R Subscapularis	24	15	41	21	81	34	95	65

TABLE 2: % MVIC of selected muscles during the football throw (Kelly et al., 2002)

From these results, two specific groups of muscles responsible for the football throw were identified. Group 1 muscles were the stabilizers, or the muscles that stayed relatively stable throughout all five stages of the throw. This group included the supraspinatus, infraspinatus, all three heads of the deltoid, and the biceps. For example, a stabilizing muscle, the supraspinatus, had percent of maximal isometric contraction values of 45%, 62%, 65 %, and 87% respectively throughout the four stages (Table 2).

Group 2 muscles were the accelerators, or the muscles that were more active during the acceleration phase. This group included the subscapularis, pectoralis major, and latissimus dorsi. In contrast, an accelerating muscle, the pectrorais major, had percent of MVIC values of 12%, 51%, 86% and 79% respectively. An example seen for an accelerating muscle the pectroalis major, the accerlation phase was much greater than the cocking phases (51% vs. 86%) (Table 2) (Kelly et al., 2002).

It was concluded that the accelerator muscles were responsible for initially eccentrically contracting during the cocking phase. This eccentric contraction produces a stretch in the muscles that will actively aid in accelerating the arm later on in the throw. These muscles would then produce a large concentric contraction producing a large force to accelerate the arm. This allows for a more powerful and strong throw. Similarly, it can be concluded as well that the stabilizer muscles primarily isometrically contract in order to provide the shoulder with a stable base in which to rotate upon. Thus, these muscles act to hold the head of the humerus into the shoulder socket and to position the scapula so that the rotation can be completed without impingement.

Although this study provided initial evidence about the muscle activity of the football throw, a more extensive study in high-level athletes is still needed. In addition, the muscle activity of core and lower extremity musculature during the football throw has not been investigated. Since an effective throw must follow a kinetic chain of actions, it would be of particular interest to also understand the role of the core and lower extremity has in the football throw.

Injuries

Football quarterbacks are at risk of injury during contact events in addition to just throwing the football. This is can occur due to contact with another player or with the ground. A comprehensive study was done using the NFL injury surveillance system with all reported injuries from 1980 to 2001 (Kelly, Barnes, Powell, & Warren, 2004) . Injury to the shoulder (15.4%) is the second most common injury for the quarterback behind only head injuries. However, the most common mechanism for shoulder injury was due to direct trauma (82.3%). The most common injuries that occur due to throwing are rotator cuff tendonitis (6.1%) and biceps tendonitis (3.9%).

Baseball Pitching

The kinematics and kinetics of the baseball pitch are discussed below. Each section will provide current literature on the topic as well as discussions on how these variables may contribute to injury.

Kinematics

The movement of the baseball pitch can be split up into 6 phases of the pitch as compared to the 5 discussed in football. Fleisig described these phases as the windup, the stride, arm cocking, arm acceleration, arm deceleration, and follow through. A figure, adapted from Fleisig et al, is shown below (C. S. Fleisig et al., 1996).

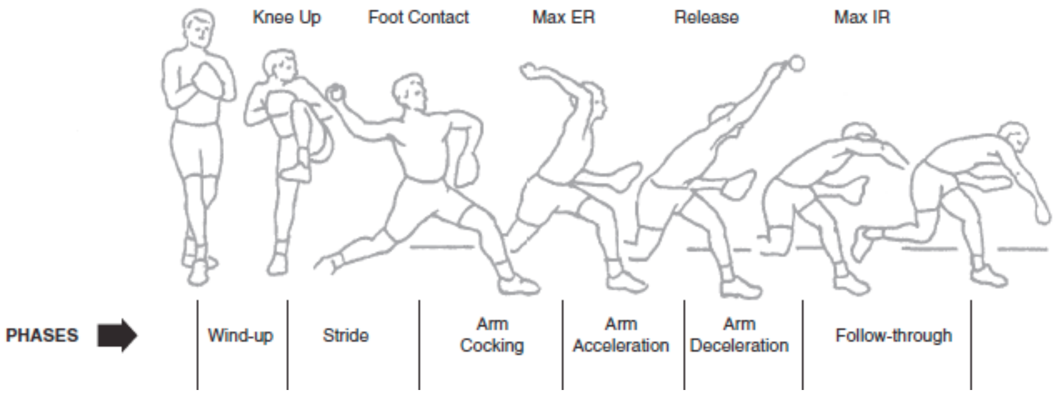


FIGURE 2: Depiction of the phases of the baseball throw. (Permission given by Fleisig et al).

Multiple studies have explored the kinematics of the baseball pitch. These studies focus mainly on how the kinematics may relate to such things as accuracy, speed, injury prevention, fatigue, and development. A summary table of the results seen from some of these studies is presented below in Table 3.

	Fleisig et al 1996	Fleisig et al 2006	Dun et al 2006
Lead Foot Contact			
Elbow Flexion	74	86	95
Shoulder Ext Rotation	67	46	48
Shoulder Horizontal Abduction	17		
Knee Flexion	51	38	39
Arm Cocking			
Maximum Elbow Flexion	100	99	106
Maximum Shoulder Horizontal Adduction	18	18	
Maximum Shoulder External Rotation	173	178	182
Ball Release			
Elbow Flexion	22	29	
Shoulder Abduction		96	
Shoulder Horizontal Abduction	7	12	
Forward Trunk Tilt	32	33	37
Lateral Trunk Tilt	34	23	18
Knee Flexion	40	29	28

TABLE 3: Kinematic Results of the Baseball Pitch as seen from three different studies (Dun, Fleisig, Loftice, Kingsley, & Andrews, 2007; C. S. Fleisig et al., 1996; G. S. Fleisig et al., 2006)

For many of the studies on baseball, much of the focus has been on the mechanics of the upper body. Few studies have focused on kinematics of the lower body. The lower body is commonly thought of as being the foundation of the pitch. This is due to its role in being the first variable in the kinetic chain of movement of the throw. It has been previously reported that maximum wrist velocity is highly correlated to the maximum push off force of the throwing leg. While the back leg provides the push off force, the lead leg is responsible for transmitting the energy up the body to maximize power output (MacWilliams, Choi, Perezous, Chao, & McFarland, 1998). Thus, it has been hypothesized that having a properly flexed knee at foot contact allows for efficient rotation of the upper torso (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001). As seen from the table above, the normal amount of knee flexion seen at this instance is between 38° and 51° (Dun et al., 2007; C. S. Fleisig et al., 1996; G. S. Fleisig et al., 2006). This flexion allows for an angular extension velocity to occur allowing the energy to be transferred to the body.

After the lead leg has properly transferred the energy, the next link in the kinetic chain is rotation of the pelvis and shoulders of the torso. A critical component of this link in the kinetic chain is the timing at which it occurs. In order to maximize the efficiency of the system, proper timing must be utilized between the rotation of the pelvis and the upper trunk. If the normalization is defined such that initial foot contact occurs 0% and ball release at 100%, then the normal time of the peak pelvis velocity is 28% to 35 % and the peak upper trunk rotation velocity is between 47% and 53% (9,17,26).

After the proper timing for trunk rotations, the next link in the chain is the shoulder. Shoulder kinematics in addition to the kinematics of the elbow is the most concentrated variables of interest. At the instance of foot contact, in order to maximize ball velocity the pitcher must try to increase the horizontal abduction while decreasing external rotation. The pitcher must do this while in addition maintaining the upper arm in a abducted angle (R. Escamilla, Fleisig, Barrentine, Andrews, & Moorman III, 2002). These values were found to be 17° (C. S. Fleisig et al., 1996) and between 46° and 67° respectively (Dun et al., 2007; C. S. Fleisig et al., 1996; G. S. Fleisig et al., 2006).

During the arm cocking phase, the most important factor in terms of velocity is to optimize the amount of external rotation (R. Escamilla et al., 2002). The optimal angle to reach for external rotation is demonstrated to be between 173° and 182° (Dun et al., 2007; C. S. Fleisig et al., 1996; G. S. Fleisig et al., 2006). Just prior to the pitcher moving to the acceleration phase and reaching maximal external rotation the elbow starts to extend (Matsuo et al., 2001). This is different than the football throw, where the elbow extends after internal rotation. Just after maximal external rotation, the pitcher must be able to reach peak shoulder internal rotation velocities close to ball release. Proper timing has shown peak to occur at 102.3% of the throw or just after release (Matsuo et al., 2001). Once at ball release, the main goal is to maintain the arm at the proper release angle. The combination of shoulder abduction and lateral trunk tilt can create the proper slot (Fortenbaugh, Fleisig, &

Andrews, 2009). A study based on simulation of biomechanical data suggests that a narrow range near 90° of abduction would be able to properly place the shoulder during this time (Matsuo, Matsumoto, Mochizuki, Takada, & Saito, 2002).

Kinetics

This section will review the kinetics of both the throwing shoulder and elbow during a baseball pitch. Several studies have been completed that have produced similar results (C. S. Fleisig et al., 1996; Glenn S Fleisig, Andrews, Dillman, & Escamilla, 1995; Werner, Fleisig, Dillman, & Andrews, 1993). The current discussion into the kinetics of the baseball throw will be centered on the injuries that are seen in both the elbow and the shoulder and how these can be explained through the kinetics. A summary table of the findings of a few of the many articles pertaining to the kinetics of the baseball throw can be seen in Table 4.

	Fleisig et al. 1996	Werner et al. 1993	Feltner and Dapena 1986	Fleisig et al 1995
Arm Cocking				
Shoulder				
Maximum Anterior Shear Force (N)	380			310
Maximum Compressive Force (N)	660			
Maximum Horizontal Adduction Torque (Nm)	100		110	82
Maximum Internal Rotation Torque (Nm)	67		90	54
Elbow				
Maximum Medial Shear Force (N)	300			280
Maximum Varus Torque (Nm)	64	120	100	51
Maximum Elbow Extension Torque (Nm)		40	20	
Arm Acceleration				
Elbow				
Maximum Anterior Shear Force (N)	360		320	
Maximum Flexion Torque (Nm)	61	55		47
Arm Deceleration				
Shoulder				
Maximum Posterior Shear Force (N)	400			240
Maximum Inferior Shear Force (N)	310			
Maximum Compressive Force (N)	1090		860	850
Maximum Adduction torque (Nm)	83			79
Maximum horizontal abduction torque (Nm)	97			85
Elbow				
Maximum Anterior Shear Force (N)	260			
Maximum Compressive Force (N)	900	780	830	710

TABLE 4: Summary of the kinetics of the baseball pitch as shown in a four different studies (Feltner and Dapena, 1986, Werner, Fleisig et al. 1993, Fleisig, Andrews et al. 1995, Fleisig, Escamilla et al. 1996)

The majority of injuries from a pitcher occur at the elbow and the shoulder (Brown, Niehues, Harrah, Yavorsky, & Hirshman, 1988). The majority of these injuries are due to some abnormality in their kinetics during the throw. The instant of maximum external rotation as well as ball release has previously been pointed out as being instances that are critical for upper body kinematics (Feltner and Dapena, 1986). Fleisig et al has gone on to name numerous kinetic variables that are critical and have been implicated in injuries (Feltner and Dapena, 1986).

In regards to the elbow joint, one of the most important kinetic variables to evaluate is the valgus torque. Excessive valgus torque can lead to medial elbow injuries, including ligament tears. These injuries frequently occur on the ulnar collateral ligament (UCL). This type of injury has seen a recent surge in amount of injuries and requires a surgery popularly known as "Tommy John Surgery." In order to prevent excess valgus torque, the pitcher must produce a varus torque at the elbow. As seen from the studies above, the varus torque at the elbow ranges from 51 to 120 Nm in the arm cocking phase. The instance at which this torque is produced has been characterized as being the instance at which the elbow is at 95° (Glenn S Fleisig, Barrentine, Escamilla, & Andrews, 1996). A study done on cadavers indicated that with the elbow flexed at 90° the UCL was able to generate 54% of the varus torque needed to resist the valgus torque (Morrey & An, 1983). Thus, given the above examples of varus torques, the UCL is providing close to 34 to 100 Nm of that varus torque. An additional cadaver study indicated that the UCL begins to fail at 32.1 ± 9.6 Nm (G. S. Fleisig et al., 1996). This indicates the UCL is working at almost maximum capacity during the pitch.

In regards to the shoulder joint, a major concern for pitchers is the tearing of the labrum. Labral tears occur from the translation and subluxation of the humeral head in the anterior and posterior direction. This results in entrapment of the labrum between the humeral head the glenoid rim (J. R. Andrews, Kupferman, & Dillman, 1991). Thus, proper anterior-posterior forces are required for a successful throw. An anterior shear force, as seen in Table 4, of 310 to 380 N is needed during the arm cocking phase. A shift is then seen to proper posterior force in the deceleration phase. A force between 240 and 400 N was shown to be normal.

Another major shoulder injury concern for baseball pitchers are injuries to the rotator cuff muscles. It has been observed that most rotator cuff injuries occur due to the attempt of these muscles to resist distraction, horizontal adduction, and internal rotation during the deceleration phase (James R Andrews & Angelo, 1988). In order to properly control these kinetics, pitchers will produce a compressive force and horizontal abduction torque during the deceleration phase (G. S. Fleisig et al., 1996). Normal compressive forces reported in Table 4 range from 850 to 1090 N, while the horizontal abduction torque ranges from 85 to 97 Nm.

Electromyography

Numerous have investigated the muscle activity during the baseball throw using electromyography (EMG) (Campbell, Stodden, & Nixon, 2010; DiGiovine, Jobe, Pink, & Perry, 1992; R. F. Escamilla & Andrews, 2009). To facilitate the discussion of the results of these studies, the previously described phases of the baseball pitch will be used to organize the EMG results.

The EMG activity during the windup phase of the throw has been shown to be very minimal for the upper extremity muscles. This is believed to be due to the very slow movement accompanied by this phase. The muscles that have been seen to be the most active during this stage are the upper trapezius, seratus anterior, and anterior deltoid (R. F. Escamilla & Andrews, 2009). These muscles cause the upward rotation of the scapula that helps abduct the shoulder in this phase.

During the stride phase, there is a large increase in the amount of muscle activity. In this phase all of the scapular muscles exhibit moderate to large activity. In addition, large to medium activation is shown in most of the glenohumeral muscles, including the deltoids and the rotator cuff muscles. The supraspinatus is particularly active during this phase (DiGiovine et al., 1992). These muscles become active to aid in the upward rotation of the scapula as well as the multiple movements of the shoulder including abduction, external rotation, and horizontal abduction (R. F. Escamilla & Andrews, 2009). The high activity of the subscapularis is mainly due to it's role in compression and stabilization of the glenohumeral joint (DiGiovine et al., 1992).

When the pitcher enters into the arm cocking phase, the majority of the muscle activity in the scapular muscles occurs via the serratus anterior (DiGiovine et al., 1992). This high muscle activity in the serratus anterior is needed in order to stabilize the scapula and properly position the scapula to help aid in shoulder abduction and rotation (R. F. Escamilla & Andrews, 2009). In addition, during this phase a large amount of activity occurs in the rotator cuff muscles (DiGiovine et al., 1992). Once again, this high activity of the rotator cuffs occurs to help stabilize and resist the glenohumeral distraction that is trying to occur (R. F. Escamilla & Andrews, 2009). The other muscles that are seen to be highly active during this phase are the pectoralis major and latissimus dorsi (DiGiovine et al., 1992). The latissiumus dorsi eccentrically contract to control the rate of shoulder external rotation as well as to prepare to accelerate the arm in the next phase. The pectoralis major contracts heavily to help horizontally adduct as well as also help eccentrically control external rotation (R. F. Escamilla & Andrews, 2009). Additionally, similar to the latissimus dorsi, this muscle eccentrically contracts to stretch the muscle and prepare for acceleration.

The arm acceleration phase shows high amounts of activity in all of the scapular muscles. The posterior deltoid, subscapularis, pectoralis major, and latissimus dorsi all exhibits a large to moderate amount of activity during this phase (DiGiovine et al., 1992). These are all contract concentrically to help provide rapid internal rotation of the shoulder. The subscapularis is also used to help maintain the humeral head in the glenoid (R. F. Escamilla & Andrews, 2009). The triceps have also been shown by some studies to produce a large amount of activity during this phase (DiGiovine et al., 1992). This high amount of activity could be due to the elbow extension that occurs during this phase (R. F. Escamilla & Andrews, 2009). However, it is not fully understood whether the extension of the elbow is due to the triceps or just results of the humerus stopping causing the forearm to extend. Additionally, the gastrocnemius, biceps femoris, rectis femoris, vastus medialis, and gluteus maximus in the trail leg all shown high activity during this phase (Campbell et al., 2010). This generates the force needed in order to propel the body forward. Interestingly there is also activation of these same muscles the stride leg (Campbell et al., 2010). This activity is due to the large force experienced from the stride by making contact with the ground.

During the arm deceleration phase, the goal is to slow down the rapid internal rotation velocity that was generated during the acceleration phase. Thus, posterior muscles, including posterior deltoid and terres minor are highly active

(DiGiovine et al., 1992). These muscles contract eccentrically to decelerate the horizontal adduction and internal rotation of the arm (R. F. Escamilla & Andrews, 2009). The biceps brachii generates their highest force during this phase (DiGiovine et al., 1992) in order to help decelerate the elbow extension as well as work with the rotator cuffs to resist distraction of the shoulder joint (R. F. Escamilla & Andrews, 2009).

The last phase, or the follow through phase, produces minimal activity in all the upper extremity musculature (DiGiovine et al., 1992). By the end of the arm deceleration phase, the majority of the internal rotation and horizontal adduction velocity are minimal. Thus, not much activity is needed and very little injuries occur during this phase.

Summary

The previous section explored the current literature on the topic of overhead throwing. In this section, there was a discussion on the kinematics, kinetics, and electromyography of the football throw. This discussion also continued on the prevalence of injuries seen in the quarterback. The chapter then explored similar parameter of kinematics, kinetics, and electromyography, but now in the baseball pitch. These sections provided information pertaining to maximizing pitch velocity as well as the kinetics responsible for injury. All of this information together is able to give a comprehensive framework of the mechanics of the overhead throw in general.

CHAPTER THREE

Methods

The purpose of this paper was to provide a detailed analysis of the football throw as it pertains to kinematics, kinetics, and electromyography. The purpose of this chapter will be to discuss the methodology used for this study. In doing so, a description of the participants, equipment, marker and electrode placement, protocol, and analysis will be discussed.

Methodology

Participants

The subjects for this study were quarterbacks on a NCAA Division I football team. Three quarterbacks participated in this study. All subjects were between the ages of 18-24 and right handed. All subjects were recruited without any influence from coaches, trainers, etc. The subjects all provided informed consent before participating in the study.

Equipment

A set of 11 high speed digital cameras (Motion Analysis Corporation, Santa Rose, CA, USA) was used to collect marker position data for this study. The motion capture data was sampled at a rate of 240 Hz. Three dimensional position data of the subject markers were determined using Cortex software (Motion Analysis, Corp, Santa Rosa, CA). In addition, two force platforms (Bertec Corp, Columbus, OH) were used to collect ground reaction forces for this study. Figure 3 below shows an image from Cortex displaying the setup of the force platforms as camera positioning for the study.

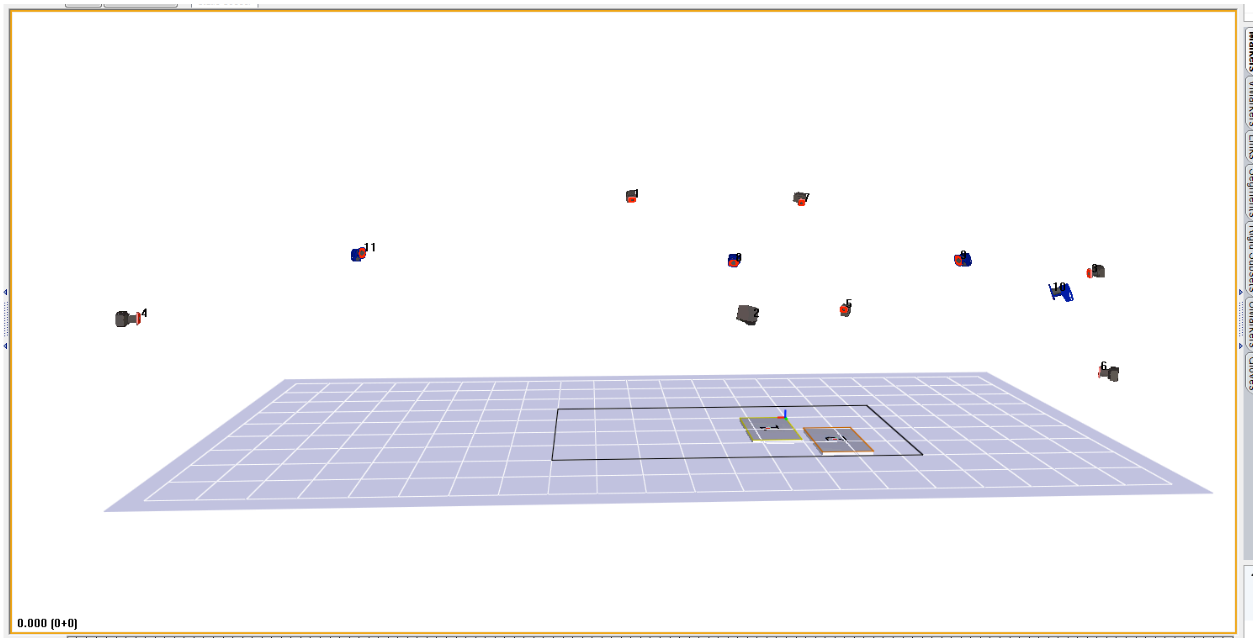
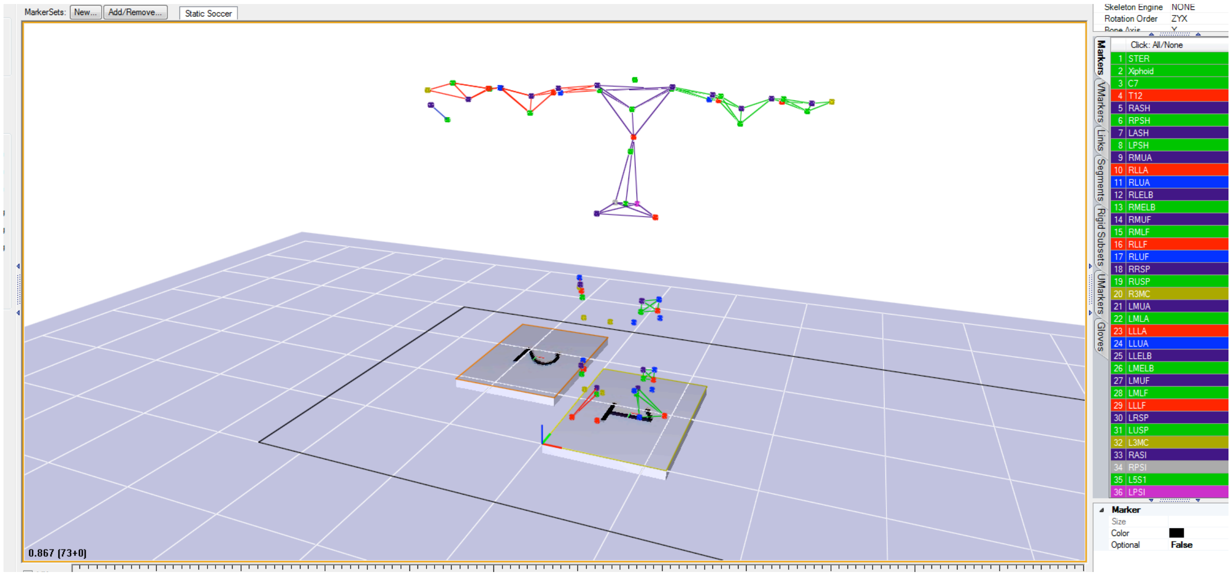


FIGURE 3: Cortex depiction of the setup of the biodynamics laboratory with positions of the force platforms and cameras.

The sampling rate for the force platforms was set at 1440Hz. The system used to collect EMG data was the Bagnoli-16 Desktop EMG system (Delsys, Boston, MA, USA). The data for the EMG were also sampled at a rate of 1440 Hz. The amplitude for each electrode was adjusted so to not saturate the signal. The electrodes used were surface Delsys single differential electrodes. The electrodes were rectangular, polycarbonate electrodes with a contact spacing of 10mm.

Marker Placement

A set of 72 retro reflective markers was placed on the subjects in order to create an anatomically relevant coordinate system and enable the calculation of meaningful kinematic and kinetic and data. The retro-reflective markers were placed bilaterally on the anterior/posterior shoulder, medial/lateral humeral condyle, ulnar styloid, radial styloid, 3^{rd} metacarpal head, ASIS, PSIS, medial/lateral femoral condyle, medial/lateral malleoli, upper/lower heel, and 1st & 5th metatarsal head. Markers were also placed on the sternum, xyphoid process, C7, T12, and L5S1. Marker clusters were then placed bilaterally on the forearm, lower arm, thigh, and shank. Offset markers were placed on the right thigh and shank. Figure 4 below shows an image from Cortex of a static calibration file. In this image, all 72 markers can be seen. After a static calibration trial establishing the anatomical coordinate system and transformations from segment clusters to anatomical coordinate system, all medial markers except for the wrist were removed.



Skeleton Engine NONE
Rotation Order ZYX

1	STER
2	Xiphoid
3	C7
4	T12
5	RASH
6	RPSH
7	LASH
8	LPSH
9	RMUA
10	RLLA
11	RLUA
12	RLELB
13	RMELB
14	RMUF
15	RMLF
16	RLLF
17	RLUF
18	RRSP
19	RUSP
20	R3MC
21	LMUA
22	LMLA
23	LLLA
24	LLUA
25	LLELB
26	LMELB
27	LMUF
28	LMLF
29	LLLF
30	LRSP
31	LUSP
32	L3MC
33	RASI
34	RPSI
35	L5S1
36	LPSI

Marker
Size
Color
Optional False

FIGURE 4: Cortex depiction of the marker placement of the subjects during a static file.

Reflective tape was used as markers for both tips of the football. Figure 5 below shows how the football was marked for this study. In addition, Figure 4 above shows the ability of the Cameras to detect the reflective tape. The same football was used for each subject at each day throughout the study.

FIGURE 5: Picture of the football used in the study including the reflective tape.

A model was developed using anatomical references to establish an anatomical coordinate system. A transformation was then established from the local to lab coordinates using a series of Cardan rotations in the order flexion/extension, abduction/adduction, internal/external rotation (XYZ). However, for the shoulder the Euler rotation ZXZ (internal/external rotation, abduction/adduction, internal/external rotation) was used for the transformation. Please reference the Appendix for greater detail regarding the model used for each segment.

Electrode Placement

The surface EMG electrodes were placed on the throwing arm, core, and lower extremity of the subject. Sixteen muscles were measured for this study. These muscles are the biceps brachii, triceps brachii, anterior deltoid, posterior deltoid, pectoralis major, latissimus dorsi, serratus anterior, infraspinatus, external oblique, rectus abdominus, internal oblique, gluteus maximus, vastus lateralus, and erector spinae. Table 5 below gives a description of the placement of each electrode. Electrode placements were determined using the recommendations from SENIAM.

Muscle	Location	Muscle	Location
Serratus Anterior	Line from level of inferior angle of scapula. Between latissimus dorsi and pectoralis major	**Infraspinatus**	With the arm and elbow will be flexed at 90 degre A point will be made 50% of the line from the posterior acromion to the inferior angle of scapula. The electrode will then b placed at 50% of a line fr the medial border of the scapula to the lateral border through that point
Anterior Deltoid	Placed 3.5cm below the anterior angle of the acromion	**Left External Oblique**	Approximately 3 cm later to the linea semi lunaris b on the same level of rectu abdominis electrodes
Posterior Deltoid	Placed 2cm below the posterior angle of the acromion	**Left Rectus Abdominus**	3 cm lateral to the umbilicus
Biceps Brachii	Center point of the muscle between the bicipital tendon at the elbow and the approximate location of the superior gleniod insertion site of the long head of the biceps at the shoulder	**Left Internal Oblique**	Halfway between the anterior superior iliac spi of the pelvis and the midline, just superior to t inguinal ligament
Triceps Brachii	Line from the posterior crista of acromion and the olecranon at 2 finger widths lateral to the line	**Right and Left Gluteus Maximus**	50% on the line between the sacral vertebrae and t greater trochanter. This position corresponds wit the greatest prominence the middle of the buttock well above the visible bul of the greater trochanter.
Lattisimus Dorsi	Placed 4.5 cm caudal to the inferior angle of scapula	**Right and Left Vastus Lateralis**	Placed at 2/3 on the line from the anterior spina iliaca superior to the later side of the patella.
Pectoralis Major	Placed 3.5 cm medial to the anterior axillary line in parallel with muscle fibers	**Left Erector Spinae**	Approximately 3 cm later to the spinous process (actually longissimus and iliocostalis at L3

TABLE 5: Electrode placement for all sixteen muscles.

Protocol

Subjects were brought to the Biodynamics Laboratory at the start of the football season. Each testing session took approximately 1 hour. Before the start of the testing each subject signed an informed consent. Markers and electrodes were then placed on the subject in a manner described above. Subjects were initially scheduled to come to the lab 4 times during the course of the season. Due to subjects' inability to make all four scheduled meetings due to their football commitments, only the initial meeting is used for this study.

Before recording any throws as trials, each subject was given adequate time to warm up and become familiar with the equipment and the surroundings. A warm up consisted of unlimited amount of throw and catch with a researcher. After the subject indicated he was ready, a total of 10 successful throws were recorded. A successful throw consisted of a 3-step drop, with the final back foot plant landing on the back force platform. The subject threw the ball approximately 10 yards into a target positioned on a net. The height of the target enabled a simulation of a longer downfield throw of approximately 20-30 yards. At the end of the throw, the participant's front foot or stride foot was required to land on the front force platform.

Manual Muscle Testing

After all the throws were successfully completed, a series of manual muscle tests were performed on each muscle. These manual tests were used to elicit a maximum voluntary isometric contraction (MVIC) for each muscle. The following table indicates the manner in which all the manual muscle tests were performed.

Muscle	Movement	Resistance
Serratus Anterior/Anterior Deltoid	With the arm 120° of flexion the subject will be instructed to punch forward.	The tester will provide resistance by pushing on the arm in a downward motion and pushing the arm towards the back
Posterior Deltoid	With the shoulder and elbow both at 90° of flexion and the shoulder at 90° of horizontal abduction the subject will be instructed to horizontally abduct at the shoulder.	The tester will apply pressure against the arm in horizontal adduction direction.
Biceps Brachii	With elbow at 90° of flexion the subject will be instructed to curl upward.	The tester will provide resistance to the flexion movement by pushing downward on the forearm.
Triceps Brachii	With elbow at 20° of flexion the subject will be instructed to extend at the elbow.	The tester will provide resistance to extension movement by pushing forward on the forearm.
Latissimus Dorsi	With elbow extended and arm slightly hyperextended the subject will be instructed to adduct and extend the arm.	The tester will provide pressure in the direction of flexion and abduction.
Pectoralis Major	With the elbow extended and the shoulder flexed at 90°, the subject will be instructed to adduct the arm obliquely toward the opposite iliac crest.	The tester will proved pressure against the forearm obliquely in the lateral and cranial direction
Infraspinatus	With the shoulder extended and arm at -45° of humeral rotation the subject will be instructed to externally rotate.	The tester will provide pressure against the external rotation.
Abdominals	Subject was in supine, with hips and knees flexed 90°, feet supported, and trunk maximally flexed (ie, curl-up position)	Resistance provided at the shoulders by a tester pushing in the trunk extension direction
Right/Left Gluteus Maximus	Hip extension with the knee flexed	Against lower part of posterior thigh in direction of hip flexion
Right/Left Vastus Lateralis	Extension of the knee joint without rotation of the thigh	Against the leg above the ankle, in the direction of flexion
Left Erector Spinae	Trunk extension with hand behind head	Holds legs down. Pressure against mid-back

TABLE 6: The proper manual muscle test for all sixteen muscles.

DATA ANALYSIS

Phase Definition

There are two different phase definitions in the literature for the football throw. As mentioned previously, Fleisig et al established the phases of the throw as windup, stride, arm cocking, arm acceleration, arm deceleration, and follow through (C. S. Fleisig et al., 1996). When examining the electromyography of the throw, Kelly et al split the phases into only four sections. These were the early cocking, late cocking, arm acceleration, and arm deceleration phases (Kelly et al., 2002). For this study, a combination of the two different phase definitions was incorporated. The only phase not included in this analysis that was previously examined is the windup phase by Fleisig. This phase pertained mainly to the baseball pitchers and thus no relevance to football quarterbacks.

The quarterback throwing motion for this study was split into five phases. The first phase was the early cocking phase (ECP). This phase started with initial foot contact (IFC) of the back foot from the drop back and ended with the front foot contact (FFC) of the stride leg. The second phase was defined as the late cocking phase (LCP). This phase started at the end of the early cocking phase and went until the shoulder reached maximum external rotation (MER). The third phase was defined as the acceleration phase (AP). This phase started at the end of late cocking and proceeded until ball release (BR). The fourth phase was defined as the deceleration phase (DP). This phase went from the ball release to maximum internal rotation of the shoulder (MIR). The last phase was defined as the follow through phase (FTP). This phase lasted until the shoulder reached maximum adduction (MA). Figure 5 below shows a depiction of the 5 stages of the throw used in this study made via screen shots in Visual 3D.

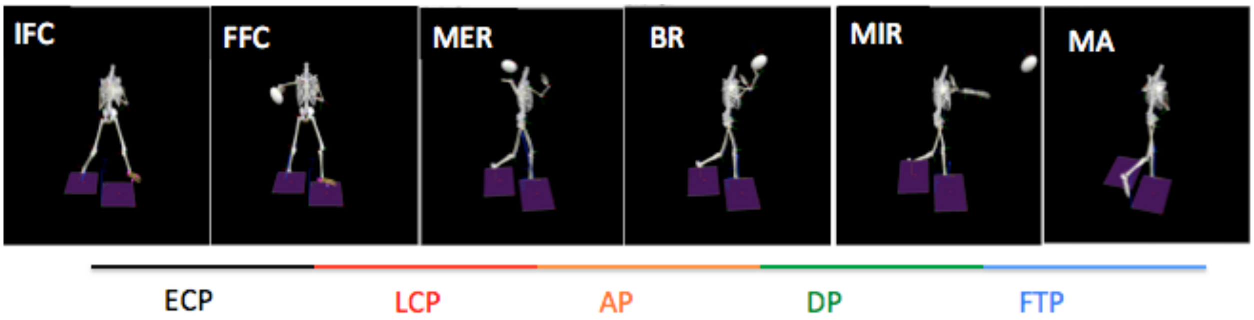


FIGURE 6: The five stages of the football throw with

In order to standardize the phases of each subject, the starting times of each phase was normalized. In this manner, the time in which each IFC, FFC, MER, BR, and MIR occurred were determined. Ball release (BR) was then used as the marker for 100% of the football throw as seen in previous literature (C. S. Fleisig et al., 1996). Each time for the other phases was then normalized to correspond with BR as 100%.

Kinematic Variables

The kinematic variables of interest for this study will be similar to those explored by Rash and Shapiro as well as Fleisig et al (C. S. Fleisig et al., 1996; Rash & Shapiro, 1995). Thus, these variables will be concentrated on the throwing shoulder and elbow, the thorax, and the lead leg. The angles are defined as follows and were calculated using Visual 3 D (C-Motion,Inc., Germantown, MD). The X-Y-Z global coordinate system followed the right hand rule system.

The shoulder angle was defined as the right upper arm relative to the thorax. From this orientation, movements about the x-axis were considered horizontal abduction (-) and horizontal adduction (+). Movements about the y-axis were defined as abduction (-) and adduction (+). Zero degrees corresponded to a fully adducted shoulder. Lastly, movements about the z-axis were that of internal (+) and external (-) rotation. A depiction of the shoulder axis from Visual 3D is depicted in Figure 6.

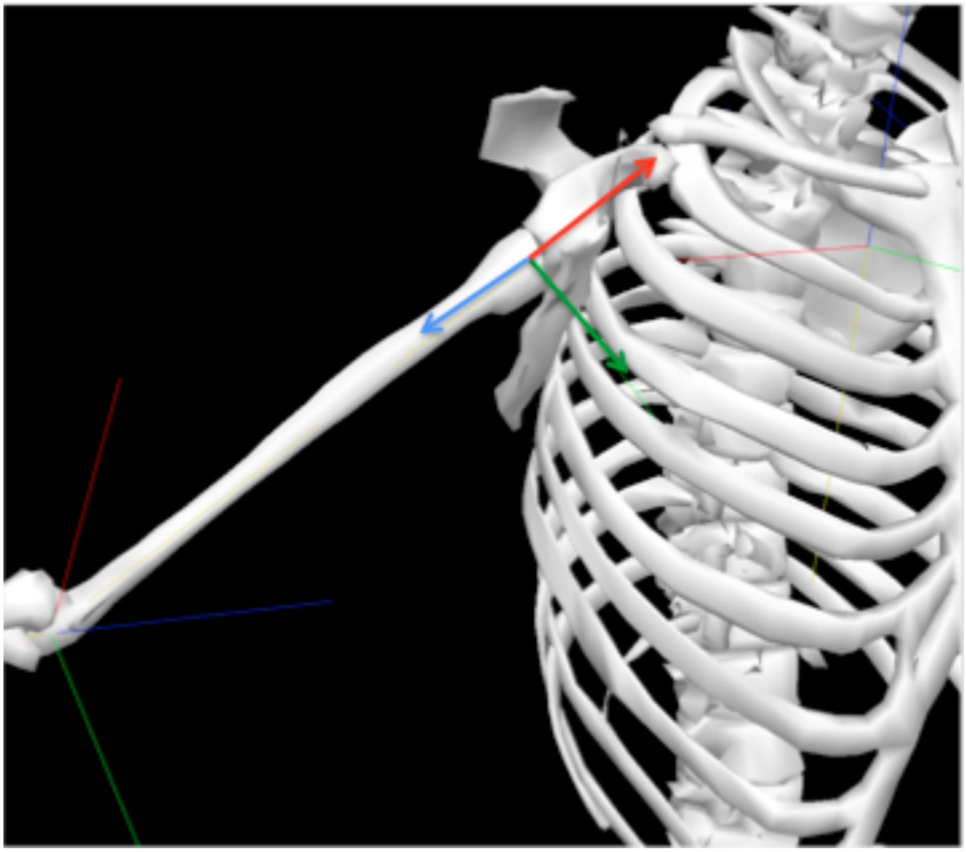


FIGURE 7: A graphical depiction of the shoulder angle in visual 3D with the X (red), Y (green), and Z (blue) axis labeled.

The elbow angle was defined as the right forearm relative to the right upper arm. From this angle, the main movement of interest was the flexion and extension of the elbow. This movement occurred about the x-axis with the movement always occurring in the positive plane. For this angle, zero degrees corresponded to a completely extended elbow. A depiction of the elbow axis as seen in Visual 3D are displayed in Figure 7.

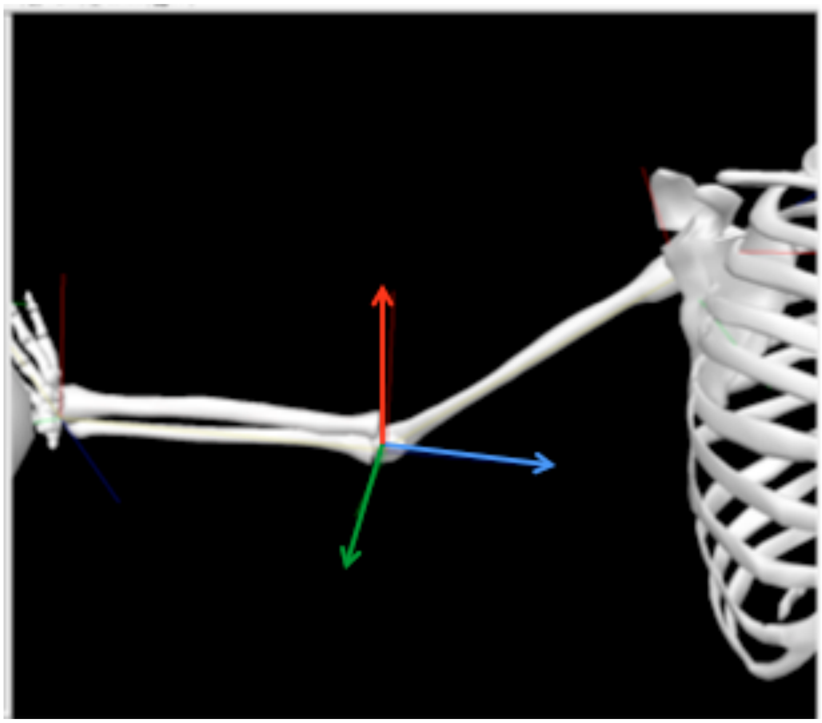


FIGURE 8: A graphical depiction of the elbow angle in visual 3D with the X (red), Y (green), and Z (blue) axis labeled.

The thorax angle was defined the thorax relative to the lab. The movements of interest in this angle were about the x and y axis. The x-axis corresponded to forward (-) and backwards (+) lean with Zero degrees corresponding to standing straight vertical. The y-axis corresponded to right (-) and left (+) lean with zero degrees corresponding to a straight vertical thorax. Figure 8 below shows the rotational axis of the thorax as depicted in Visual 3D.

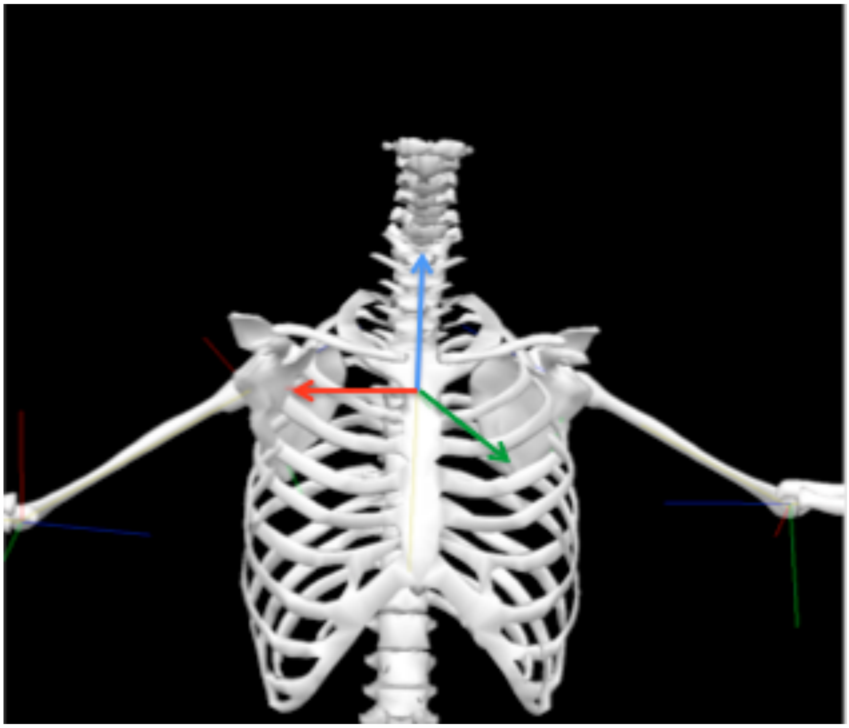


FIGURE 9: A graphical depiction of the thorax in visual 3D with the X (red), Y (green), and Z (blue) axis labeled.

The lead knee angle was defined as the left shank relative to the left thigh. Similar to the elbow, the main variable concerned with the angle occurred about the x-axis. This plane produced flexion (-) and extension (+) movements. All movements for this angle occurred in the negative direction with zero degrees being full extension. Figure 9 below shows the axis of rotation of the lead knee as shown in Visual 3D.

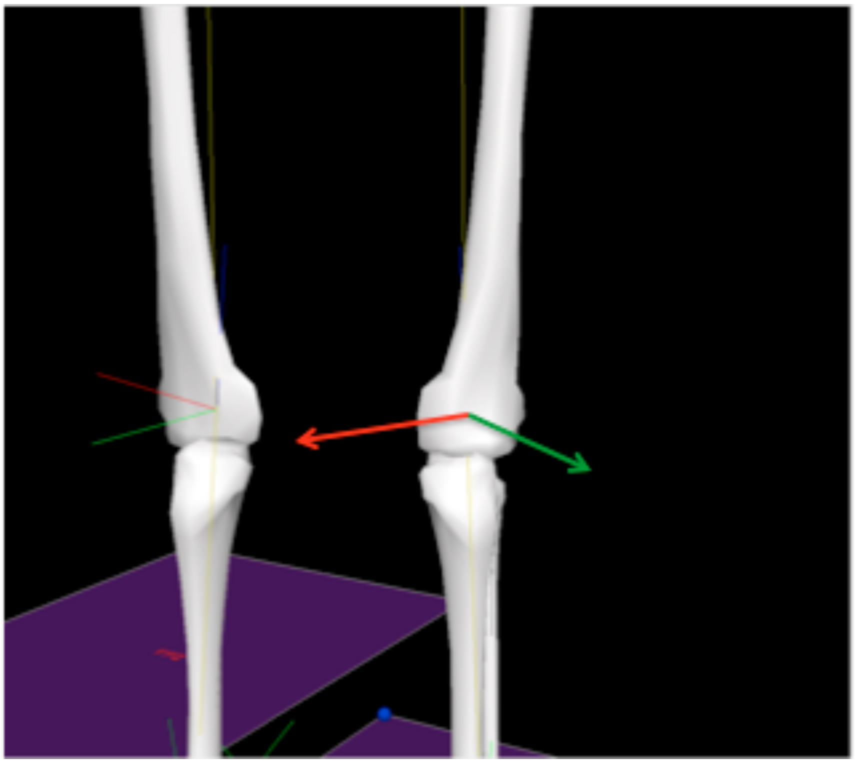


FIGURE 10: A graphical depiction of the knee angle in visual 3D with the X (red) and Y (green), axis labeled.

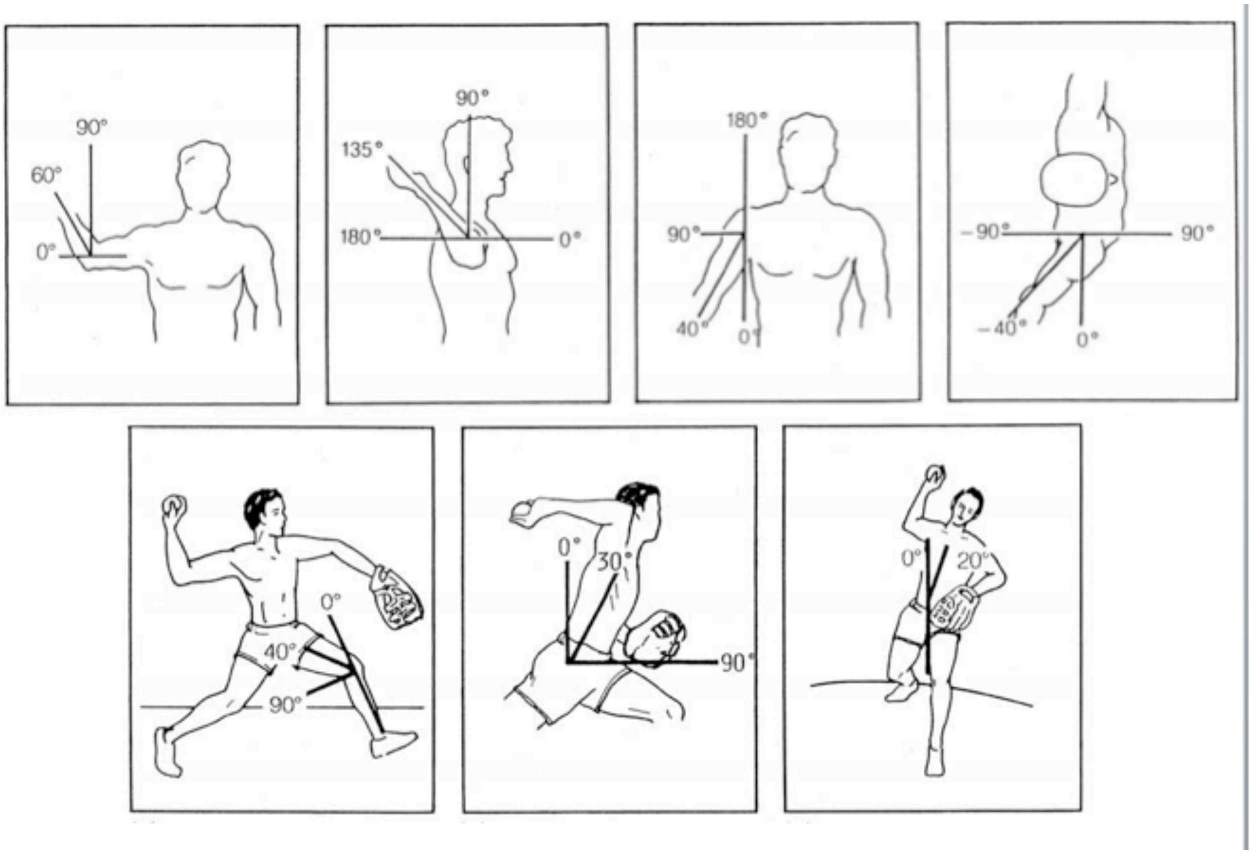


FIGURE 11: Graphical depiction of examples of different angles in each kinematic category. (R. F. Escamilla et al., 2007)

All the angles of importance are given in Figure 10 which is used with permission from a figure in Escamilia et al (R. F. Escamilla et al., 2007). As seen in this figure, a definition of where each angle is equivalent to 0° is given. Additional example angles are also presented in the figure.

All angles were calculated using a Cardan sequence of flexion/extension, ab/adduction, and internal/external rotation (X-Y-Z) with the exception of the shoulder. For the shoulder, a Cardan rotation sequence of internal/external, ab/adduction, flexion/extension (Z-Y-X) was used as this sequence produced the most meaningful shoulder rotation data with a minimum of gimbal lock.

Kinetic Variables

The kinetic variables of interest were also similar to those explored by Rash and Shapiro (Rash & Shapiro, 1995) as well as Fleisig (C. S. Fleisig et al., 1996). Thus, these variables will be concentrated on the throwing shoulder and elbow. The program Visual 3D was used to compute both forces and torques variables.

The shoulder moments or torques were defined as the right shoulder with the resolution coordinate system was the thorax. From this orientation, torques in the x-plane was considered horizontal abduction and adduction torques. Rotations about the y-axis were defined as abduction (-) and adduction (+) torques. Lastly, rotations about the z-axis were that of internal (+) and external (-) rotation torques.

The elbow moments were defined as the right elbow with the resolution coordinate system as the right upper arm. From these torques, the interests were the flexion and varus torques of the elbow. The flexion torques occurred about the x-axis while the varus torques occurred about the y-axis.

Electromyography Variables

All processing for EMG was completed with the same standards provided by the Visual3D software. Before determining the %MVIC for each muscle the data was processed. The data was filtered with a low pass filter of 500Hz and a high pass filter of 20Hz effectively creating a band pass filter. After filtering, root mean processing was used in order to rectify the data.

The level of muscle activity level was also investigated using the maximum voluntary isometric contractions (MVIC) for comparison. The MVIC was the maximal muscle activity of each muscle during the manual muscle tests presented in Table 2. The maximal output for each muscle that would be used to normalize was determined over all MVIC tasks and not just the specific task for the muscle. Before beginning, the EMG data were processed the same as when determining the onsets and offsets. After the data were processed, the maximum output for each muscle was determined for the early cocking, late cocking, acceleration, and deceleration phases of the throw. These maximal values were then compared in relation to the maximal value that had previously been determined for each muscle through the manual muscle tests. Thus, each muscle's activity became a percentage of maximal output during that particular phase. This manner of presenting the data was similar to that of Kelly et al (Kelly et al., 2002).

Statistical Analysis

The current study was a descriptive analysis of the football throw as it pertains to kinematics, kinetics, and electromyography. Descriptive statistics were used to represent the data.

CHAPTER FOUR

The current study examined the collegiate football throw. In order to describe the football throw, the kinematics, kinetics, and selected muscles were investigated. All of these parameters together provide an all-encompassing view of the biomechanics of the football throw. Chapter four of this report will focus specifically on the results of the current study.

Results

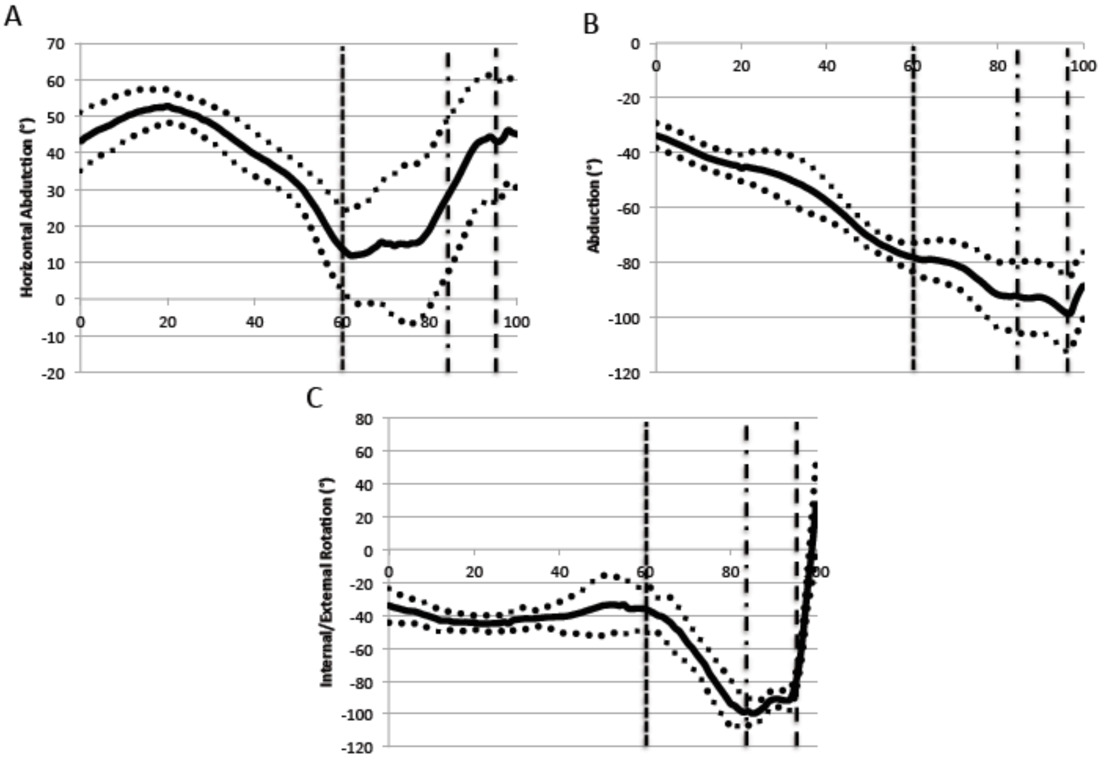
The results for this study will be organized into kinematic, kinetic, and electromyography sections. These sections will be further broken into the body segments examined as well as the phase of the throw. Both graphs and tables will be used in this chapter.

Kinematics

Notable angle graphs are displayed in this section as well as a table of significant values during the phases of the throw similar to that displayed by Fleisig (C. S. Fleisig et al., 1996). The data were normalized such that for graphical data, point 0 corresponds to initial foot contact (IFC), point 60 to front foot contact (FFC), point 83 to maximum external rotation (MER), point 94 to ball release (BR), and point 100 to maximum internal rotation (MIR) of the shoulder.

Shoulder

Below in Figure 11 is a time-angle graph for three shoulder rotations of the throwing arm during the football throw. Included in the graph is the mean of all the quarterbacks (solid black line) and +/- one standard deviation (black dotted line). Figure 11a displays the horizontal abduction and horizontal adduction. Figure 11b displays the abduction and adduction of the shoulder. Lastly, Figure 11c shows the internal and external rotation of the shoulder.



FIGURES 12: Shoulder movement during the football throw with mean (solid black line) and +/- one standard deviation (dotted black line). Vertical black lines represent front foot contact (dotted), maximum external rotation (dashed), and Ball release (dotted/dashed). (A) Horizontal abduction (+) and adduction of the shoulder. (B) Abduction (-) and adduction of the shoulder. (C) Internal (+) and external (-) rotation of the shoulder

As seen in Figure 11, the shoulder is held in around 40 degrees of external rotation during initial cocking. Also during this phase, the shoulder slowly abducting from 40 to 80 degrees as well as horizontally abducting from a horizontal adducted position of 50 degrees. During late cocking phase, the shoulder remains in a relatively stable state of horizontal adduction while continuing to abduct and while undergoing approximately 60 degrees of external rotation. During the acceleration phase, the shoulder continues to abduct and starts to horizontally adduct. Also, in this phase, the amount of external rotation stays relatively stable then towards ball release experiences a rapid internal rotation. During follow through, the shoulder continues its internal rotation and horizontal adduction, while now starting to adduct.

Elbow

Figure 12 is the time-angle graph for elbow flexion and extension during the football throw of the throwing arm. Full extension of the elbow would occur at 0°.

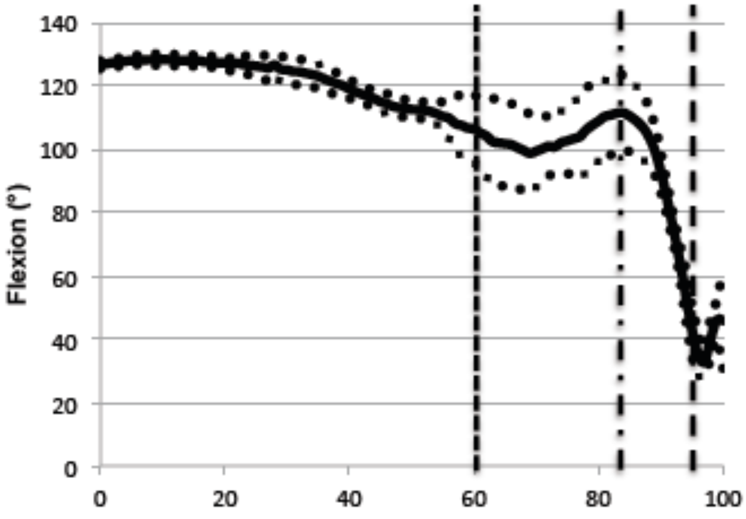


FIGURE 13: Elbow movement during the football throws with mean (solid black line) and +/- one standard deviation (dotted black line). Vertical black lines represent front foot contact (dotted), maximum external rotation (dashed), and Ball release (dotted/dashed). Flexion movement indicated in + y-axis.

As seen in Figure 12, the elbow remains in a relatively constant state of flexion throughout the early phases of the throw at about 125 degrees. At about maximal external rotation, the elbow shows to be around 110° of flexion. At this instant, the elbow experiences a rapid extension until ball release. At ball release, the elbow has extended to about 30° of flexion. Extension ceases just after release and elbow flexion is observed during the remainder of the follow-through.

Knee

Figure 13 is the time-angle graph for knee flexion in the lead leg during the football throw. Similar to the elbow, 0° is corresponded to full extension.

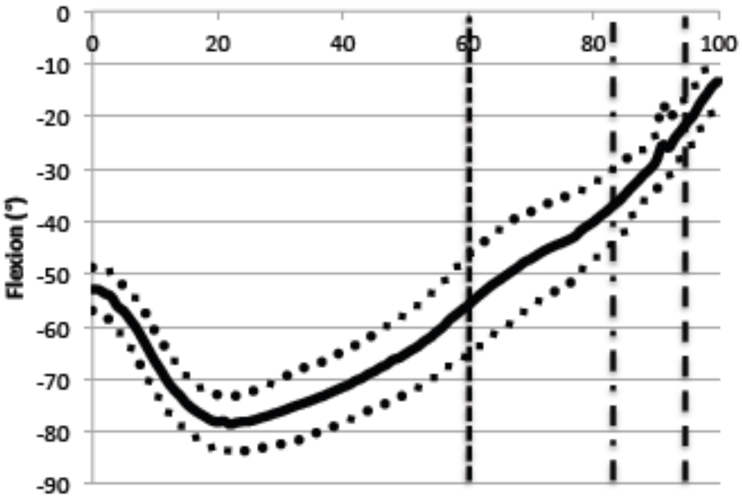


FIGURE 14: Knee flexion (-) and extension (+) during the football throws with mean (solid black line) and +/- one standard deviation (dotted black line). Vertical black lines represent front foot contact (dotted), maximum external rotation (dashed), and Ball release (dotted/dashed).

As demonstrated in Figure 13 above, the knee of the lead leg undergoes flexion through the beginning of the early cocking phase. About midway through the early cocking phase, the knee begins to extend from 80 degrees and continues on a gradual extension throughout the remainder of the throw. This gradual extension of the knee of the lead leg corresponds to the latter portion of the in air stride of the lead leg as it prepares for contact. It is worth noting in this graph that the knee of the lead leg continues to extend throughout front foot contact. The knee exhibits close to an 80-degree range of motion throughout the entire throw.

Thorax

Figure 14 displays the time-angle graphs for the thorax during the football throw. Figure 14A displays the forward tilt of the thorax. Figure 14B demonstrates the side tilt of the thorax. In both of these graphs, 0° corresponds to a vertical thorax.

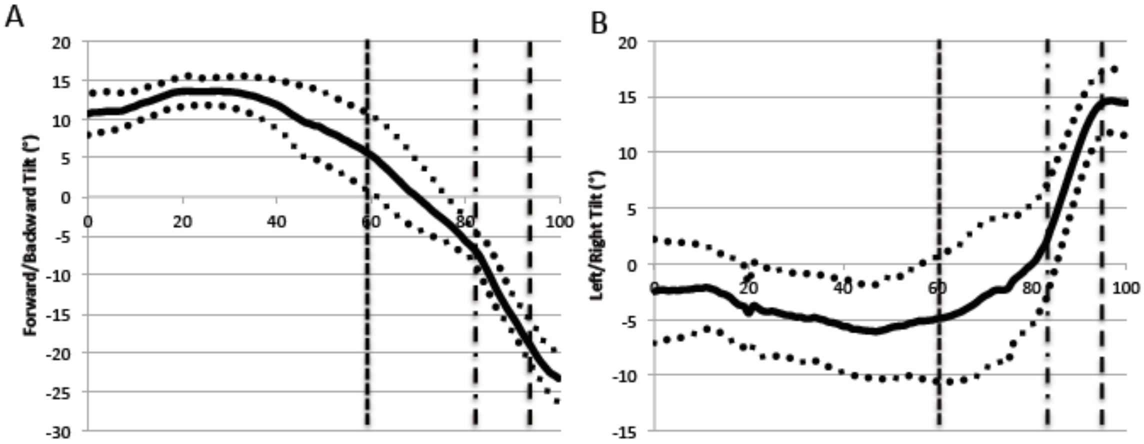


FIGURE 15: Time angle graphs for the thorax with mean (solid black line) and +/- one standard deviation (dotted black line). Vertical black lines represent front foot contact (dotted), maximum external rotation (dashed), and Ball release (dotted/dashed). (A) Forward (+) and backward (-) tilt of the thorax. (B) Left (+) and right (-) tilt of the thorax.

Figure 14 demonstrate how the thorax moves in both the frontal and sagittal planes. From these graphs, the thorax is seen to have a relative backward right lean of about 15 degrees throughout the early cocking phase. At foot contact of the front foot the torso begins to produce a forward and leftward leaning motion. These motions continue throughout the rest of the throw. The trunk goes through an excursion of about 40 degree in the sagittal plane and 20 degrees in the frontal plane. At the end of the throw during the follow through the trunk lean to the left remains constant. It is worth noting again that all participants in this study were right handed, thus all finishing the throw on the side opposite of the throwing arm.

Discrete Kinematics

Table 7 below depicts relevant kinematics that occurred during phases and instances during the throw. This table corresponds to a similar table reported in Fleisig (C. S. Fleisig et al., 1996).

Kinematics

	Mean	SD
Instant of Foot Contact		
Stride length ankle-ankle (%Height)	30	5
Shoulder Abduction (°)	83	8
Shoulder Horizontal Adduction (°)	15	7
Shoulder External Rotation (°)	14	7
Elbow Flexion (°)	97	4
Lead Knee Flexion (°)	60	6
Arm Cocking Phase		
Max Pelvis Angular Velocity (°/s)	480	36
Max Shoulder Horizontal Adduction (°)	29	18
Max Upper Torso Angular Velocity (°/s)	756	150
Max Elbow Flexion (°)	114	7
Instant of Maximum Should Ex Rotation		
Max Should External Rotation (°)	117	4
Arm Acceleration Phase		
Max Elbow Extension Velocity (°/s)	2043	172
Instant Ball Release		
Ball Velocity (m/s)	22	4
Should Horizontal Adduction (°)	36	6
Elbow Flexion (°)	63	22
Trunk Tilt Forward (°)	19	3
Trunk Tilt Side (°)	12	3
Lead Knee Flexion (°)	24	7
Arm Deceleration Phase		
Max Should Internal Rotation Velocity (°/s)	1597	364
Min Elbow Flexion (°)	47	12

TABLE 7: Kinematics of the football throw during certain instances of time. Includes mean and standard deviation.

Table 8 below reports the average timing of events during the football throw. All timing is given as a percent of the throw with ball release at 100 percent of the throw.

TIMING

	Mean	SD
Instant Foot Contact	0	0
Arm Cocking Phase		
Instant of Lead foot contact	63	3
Max Pelvis Angular Velocity	83	5
Max Up Torso Angular Velocity	83	2
Instant of Max Should Ext Rot	88	2
Arm Acceleration Phase		
Max Elbow Ext Velocity	100	4
Instant Ball Release	100	0
Arm Del Phase		
Max Should Internal Rot Velocity	106	1
Instant of Maximum Internal Rotation	106	7
Follow Through Phase		
Instant of Max Should Add	127	9

TABLE 8: Timing of kinematic measurements during the football throw. Mean and standard deviations are included.

Kinetics

Kinetic data are displayed below in tabular format. Table 9 below shows the results for the forces and torques at the elbow and shoulder calculated during different phases of the throw.

KINETICS		
Arm Cocking	Mean	SD
Max Shoulder Anterior Force (N)	313	38
Max Should Horizontal Adduction Torque (Nm)	31	7
Max Should Internal Rotational Torque (Nm)	70	4
Max Elbow Medial Force (N)	234	28
Max Elbow Varus Torque (Nm)	27	5
Arm Acceleration Phase		
Max Elbow Flexion Torque (N/m)	62	13
Arm Deceleration Phase		
Max Shoulder Compressive Force (N)	778	85
Max Elbow Compressive Force (N)	809	26
Max Shoulder Adduction Torque (Nm)	116	26
Follow Through Phase		
Max Shoulder Posterior Force (N)	299	37
Max Shoulder Horizontal Abduction Torque (Nm)	103	28

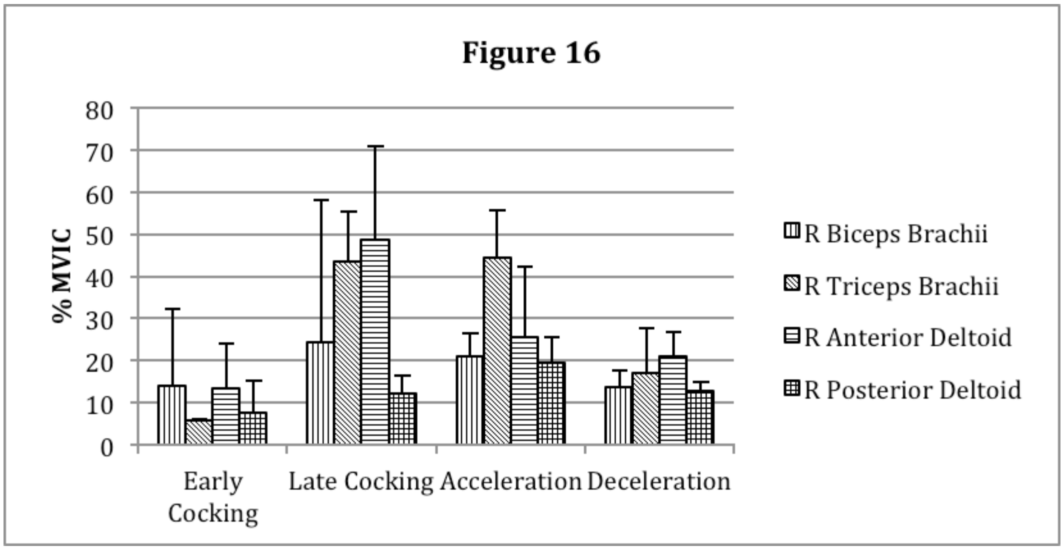
TABLE 9: Kinetics of the quarterbacks through the phases of the football throw.

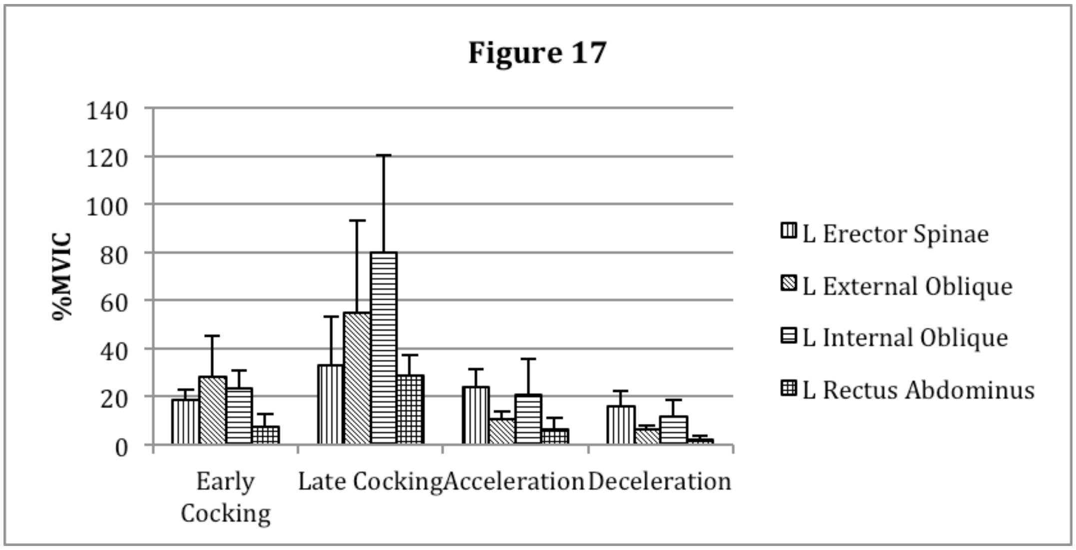
Muscle Activity

Electromyographic data was analyzed to determine the relative amount of muscle action of each muscle during each phase of the throw relative to a previously measured maximum isometric contraction.

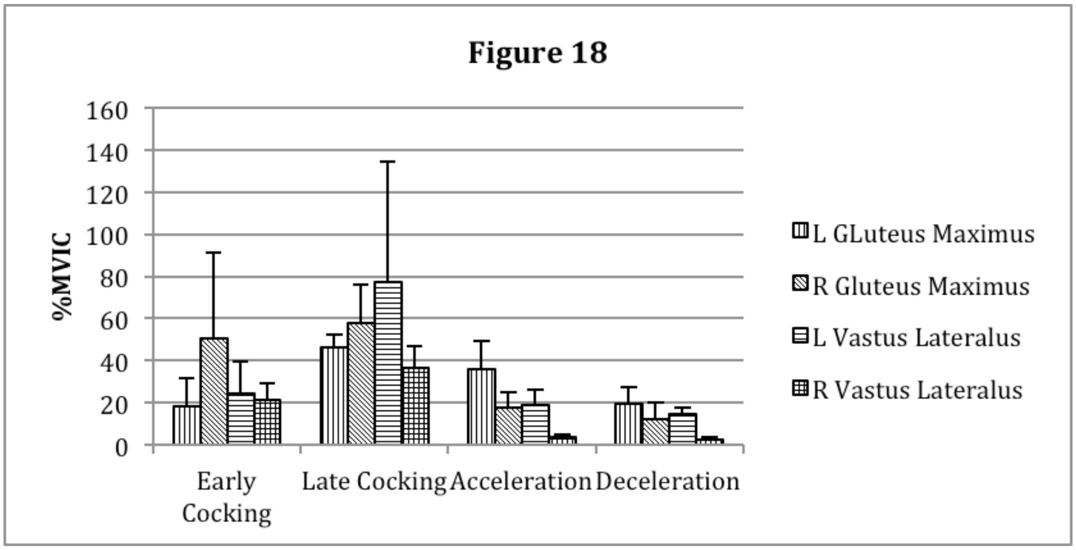
% of MVIC

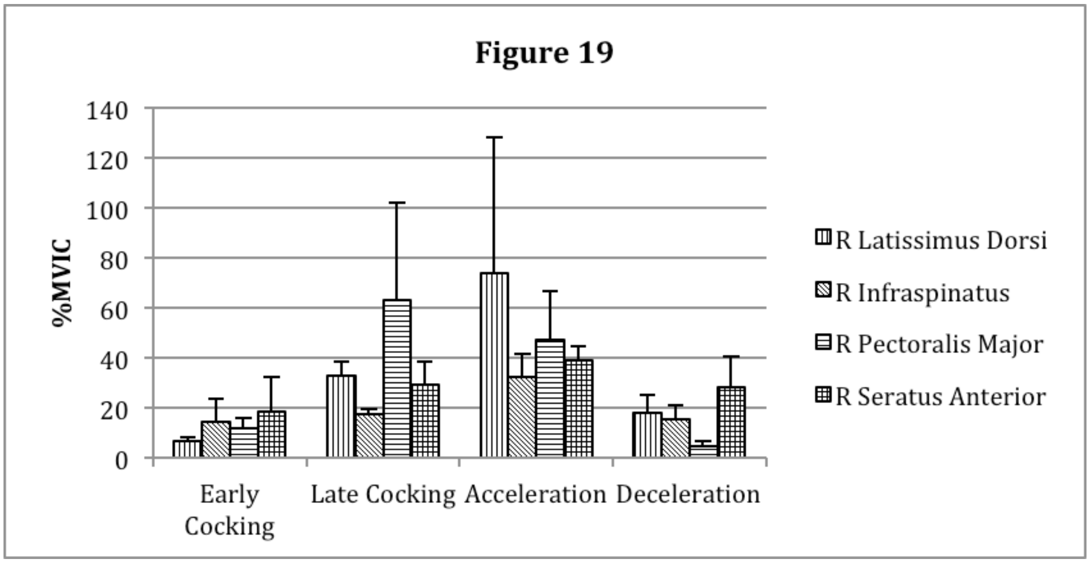
Results for the percent of maximum voluntary isometric contractions are separated for each stage of the throw as seen in Kelly et al (Kelly et al., 2002). For comparison to Kelly et al, only early cocking, late cocking, acceleration, and follow through phases were analyzed. Results are given below in figures 15-18. As discussed in Kelly et al, muscles will be considered minimally active if they are producing less than 35% of the MVIC. In addition, muscles will be considered moderately active producing between 35-70% MVIC. Lastly, muscles will be labeled as maximally active if the produce greater than 70% of MVIC.





FIGURES 16-17: Percent of MVIC during four stages of the throw.





FIGURES 18-19: Percent of MVIC during four stages of the throw.

Summary

This chapter explored the results of the current study. For this study, the kinematics was analyzed both in graphical form as well as through discrete time points. The kinetics of the throw was analyzed using discrete time points. Lastly, the muscle activity of selected upper and lower extremity as well as core muscles of the football throw was analyzed by exploring the relative amount of activity seen in each phase of the throw. These entire variables together are able to provide a comprehensive analysis of the football throw.

CHAPTER FIVE

Discussion

The purpose of this study was to provide a comprehensive analysis of the football throw. This is a novel study in that it combined kinematics, kinetics, and muscle activity data to describe the throw. Chapter five will present a discussion of the results reported in Chapter 4. This discussion will incorporate related literature to help present a complete description of the football throw. The discussion will also use previous literature to discuss the similarities and differences of the football throw and the baseball pitch. Lastly, this section will also speculate on potential injuries that could arise due to the shown kinematics.

This section will be split into discussions based on the phases of the throw. This chapter will bring all of the current results from kinematics, kinetics, and muscle activity and offer a detailed description of the movements happening during each phase of the throw. In addition, this chapter will compare and contrast the kinematic and kinetic results of the present study to the findings of Fleisig et al as well as Rash and Shapiro. Lastly, this chapter will also compare and contrast the muscle activity results of this study with those of Kelly et al. The results of this investigation will also be discussed in light of findings from other studies that have examined other overhead throwing motions such as baseball throwing and tennis serving.

Comparison to Previous Football Studies

The literature describing the biomechanics of the football passing motion is very minimal. Only two previous studies have investigated the kinematics and kinetics of football passing (C. S. Fleisig et al., 1996; Rash & Shapiro, 1995), while only one other study investigated muscle activity during the throw using electromyography (Kelly et al., 2002).

Kinematics and Kinetics

The kinematic and kinetic results from this study were reported in Tables 8-9. These results are similar to those seen in Fleisig et al (C. S. Fleisig et al., 1996) and Rash & Shapiro (Rash & Shapiro, 1995). Below in Tables 11-12 is a summary of the results seen in the current study as well as that seen in previous literature.

Kinematics

	Current	Fleisig et al	Rash & Shapiro
Instant of Foot Contact			
Stride length ankle-ankle (%Height)	30	61	-
Shoulder Abduction (°)	83	96	97
Shoulder Horizontal Adduction (°)	15	7	-1
Shoulder External Rotation (°)	14	90	47
Elbow Flexion (°)	97	77	75
Lead Knee Flexion (°)	60	39	-
Arm Cocking Phase			-
Max Pelvis Angular Velocity (°/s)	480	500	-
Max Shoulder Horizontal Adduction (°)	29	32	-
Max Upper Torso Angular Velocity (°/s)	756	950	-
Max Elbow Flexion (°)	114	113	-
Instant of Maximum Should Ex Rotation			
Max Should External Rotation (°)	117	164	164
Arm Acceleration Phase			
Max Elbow Extension Velocity (°/s)	2043	1760	-
Instant Ball Release			
Ball Velocity (m/s)	22	21	-
Should Horizontal Adduction (°)	36	26	12
Elbow Flexion (°)	63	36	121
Trunk Tilt Forward (°)	19	65	-
Trunk Tilt Side (°)	12	116	-
Lead Knee Flexion (°)	24	28	-
Arm Deceleration Phase			
Max Should Internal Rotation Velocity (°/s)	1597	4950	2987
Min Elbow Flexion (°)	47	24	-

TABLE 11: Kinematic and kinetic results of the current study as well as those seen in Fleisig et al (C. S. Fleisig et al., 1996) and Rash & Shapiro (Rash & Shapiro, 1995).

KINETICS

Arm Cocking	Current	Fleisig et al
Max Shoulder Anterior Force (N)	313	350
Max Should Horizontal Adduction Torque (Nm)	31	78
Max Should Internal Rotational Torque (Nm)	70	54
Max Elbow Medial Force (N)	234	280
Max Elbow Varus Torque (Nm)	27	54
Arm Acceleration Phase		
Max Elbow Flexion Torque (N/m)	62	41
Arm Deceleration Phase		
Max Shoulder Compressive Force (N)	778	660
Max Elbow Compressive Force (N)	809	620
Max Shoulder Adduction Torque (Nm)	116	58
Follow Through Phase		
Max Shoulder Posterior Force (N)	299	240
Max Shoulder Horizontal Abduction Torque (Nm)	103	80

TABLE 12: Kinetic results of the current study as well as those seen in Fleisig et al (C. S. Fleisig et al., 1996)

The current study produced mostly similar results compared to the previous literature on the football pass. However, there were some differences in the results of each study. One large difference seen from these studies is in the amount of movement of the thorax, as seen by trunk tilt forward and to the side during the acceleration phase. Fleisig et al. reports values of 65° of tilt to the forward and 116° to the left. However, these differences are due to how the angles were measured. In Fleisig et al. thorax angles were measured with 0° corresponding to completely bent forward parallel to the ground and completely bent to the right parallel to the ground. Thus, converted to how the angles in the present study were measured would give you 15° of forward tilt and 26° of tilt to the left, which is very similar to the current study.

One additional significant difference occurs in the value of the maximum shoulder external rotation as well as maximum shoulder internal rotation velocity seen during the deceleration phase. These values are concerning giving the similarities seen in ball velocity. As was the case with the thorax, the differences seen between the two previous articles on football kinematics and this current study can mainly be attributed to the differing ways in which the angles were calculated. Fleisig calculated the shoulder angle for external/internal rotation by using the rotation of the forearm about the upper arm's long axis (C. S. Fleisig et al., 1996). The procedure used by Fleisig was previously reported in an article by Dapena (Dapena, 1978). The drawback to this procedure was it does not seem to take into account the movement of the trunk. The current method used in this study as discussed above used the upper arm relative to the trunk. As demonstrated by Figure 14, the trunk during the late cocking phase was rotated backward as well as to the right side. As previously mentioned, this phase occurs at the start of front foot contact and continues to maximum external rotation, the instances where these differences are seen. We could hypothesize the decreased in the amount of external rotation compared to previous papers could be due to the current study not including this trunk movement in the measurement of the shoulder. This could also explain the large discrepancy seen during internal rotation velocity due to not including the trunk movement in our calculations.

Muscle Activity

As mentioned above, the study by Kelly et al is the only known article to previously examine the muscle activity during the football throw. In addition to comparing our data to this study, the current study looked to provide additional information pertaining to the muscle activity of the core and lower body. Below in Table 13 is a summary of the current results and those seen in Kelly et al (Kelly et al., 2002).

Muscle	Early Cocking		Late Cocking		Acceleration		Follow Througl	
	Current	Kelly et al	Current	Kelly et al	Current	Kelly et al	Current	Kelly e al
R Biceps Brachii	14	12	24	12	21	11	14	20
Triceps Brachii	6	-	43	-	44	-	17	-
R Anterior Deltoid	13	13	49	40	25	49	21	43
R Posterior Deltoid	8	11	12	11	19	32	13	53
L Erector Spinae	19	-	33	-	23	-	16	-
L External Oblique	28	-	55	-	10	-	6	-
L Internal Oblique	24	-	80	-	21	-	11	-
L Rectus Abdominus	7	-	29	-	6	-	2	-
L Gluteus Maximus	18	-	46	-	35	-	20	-
R Gluteus Maximus	51	-	57	-	18	-	12	-
L Vastus Lateralus	25	-	77	-	19	-	14	-
R Vastus Lateralus	21	-	37	-	4	-	2	-
R Latisimus Dorsi	7	7	33	18	74	65	18	72
R Infraspinatus	14	46	17	67	32	69	16	86
R Pectoralis Major	12	12	62	51	47	86	5	79
R Serratus Anterior	18	-	29	-	39	-	28	-

TABLE 13: Summary table of the electromyography results seen in the current study as well as Kelly et al. Numbers are expressed as a %MVIC (Kelly et al., 2002).

The results from Kelly et al grouped the nine muscles into two specific groups of muscles. Group 1 muscles were the stabilizers, or the muscles the stayed relatively static throughout all five stages of the throw. This group included the supraspinatus, infraspinatus, all three heads of the deltoid, and the biceps. Group 2 muscles were the accelerators, or the muscles that were more active during the acceleration phase. This group included the subscapularis, pectoralis major, and latissimus dorsi (Kelly et al., 2002). The present study introduced additional muscles not included in Kelly et al. The muscles not studied in this study but included by Kelley were the supraspinatus and subscapularis. The muscles only included in this study include the triceps, serratus anterior, the left and right gluteus maximus and vastus lateralus, the erector spinae, rectus abdominus, and internal and external oblique.

The results of the current study show four distinct groups of muscle as opposed to just two. Group 1 muscles are similar to the Kelly article and will also be labeled as the stabilizers. As described by Kelly, these muscles stayed relatively consistent throughout all four stages of the throw. In the present study these muscles were the biceps brachii, posterior deltoid, erector spinae, infraspinatus, and seratus anterior. Group 2 muscles are the accelerator muscles, or the muscles most active during the acceleration phase. The muscles in the current study in this group included the triceps brachii, anterior deltoid, latissiumus dorsi, and pectoralis major. The current study proposes two additional novel groups of muscles. Group 3 muscles of the current study will be called the core accelerators. This group includes the rectus abdominus, and internal and external oblique. As demonstrated by Figures 16-19, these muscles produced their greatest activity during the late cocking phase. The last group includes the lower extremity muscles. We will split this group into Groups 4a and 4b. Group 4a muscles are the leg accelerators, or the lower body muscles that produce the greatest activity during the early cocking and late cocking phases. The muscles in this group are the right vastus lateralis and right gluteus maximus. Group 4b muscles are the leg decelerators, which include the lower body musculature on the left side and produce a large amount of activity only during the late cocking phase. Further discussion of these groups of muscles will be highlighted with the phase most relevant to that group.

Phases of the Football Throw

The discussion will now center on how the results seen above in previous studies on football as well as other results from baseball compare to the current study. This discussion will be split into sections pertaining to a specific phase of the throw. The purpose of these sections will be to provide a comprehensive discussion of the mechanics that is normal during each phase of the football throw.

Early Cocking Phase

The early cocking phase of the football throw has been defined as starting initial contact followed by forward stride of the stride foot until foot contact of the stride limb. During this phase, movement in the frontal plane had the greatest amount of excursion. The first movement seen in this phase of the throw occurred in the lower extremity. As seen from Figure 13 the lead knee is in a constant amount of flexion throughout the phase. The beginning on this phase occurred with the initial contact of rear leg with the ground at the end of the drop back. In order to accomplish stabilizing the leg during stance the right gluteus Maximus becomes moderately active (51 ± 40%) and the vastus lateralis become minimally active (21 ± 8%). These muscles were described earlier as being in Group 4a of the muscles. Group 4a muscles are the leg accelerators, or the lower body muscles that produce the greatest activity during the early cocking and late cocking phases. These muscles are responsible for producing the initial stabilizing activity. In later portions of this phase, these muscles produce large activity to push off the ground and continue to contract to accelerate the leg through the stride. These forces produced from these muscles allow the kinetic chain to then produce forces in the core.

There was not much muscle activity seen in the stride leg during early cocking. As seen from Figure15, both the left vastus lateralas and gluteus maximus turn on later than the other lower extremity muscles. Since this phase began with the contact of the back or right foot while the lead leg is in the air. During the last portion of the early cocking phase, the stride leg experiences an extension at the knee before contact. For this movement to occur, the left vastus lateralis was observed to be minimally active but at a percentage of 25% ± 15% of MVIC. This movement causes the knee to be at 60 ± 6 degrees of extension at foot contact. The left knee must be flexed to clear the floor and begin the stride. Once mostly through the stride, the knee must begin to extend to prepare for front foot contact.

In regards to the trunk, during the early cocking phase the thorax leans backward and to the right side. The lean to the right is allowed by an eccentric contraction of both the left internal and external oblique. Both of these muscles are close to being moderately active with the internal oblique firing at 24 ±7% and the external oblique at 28 ± 17% during this phase. It is important to note that even though the current study defines the start of the football throw as initial rear foot contact, the football throw actually starts during the dropback of the quarterback. The momentum of the quarterback during the dropback causes these movements to the right and the back. These eccentric movements are used to control the thorax and stop the backward momentum of the trunk. This movement of the thorax elicits the stretch reflex to be able to produce a larger concentric contraction in the core muscles in later phases. These results are similar to that found by Chow in the tennis serve (Chow, Shim, & Lim, 2003). In the tennis serve, the initial phase is defined as the windup phase. This study found the highest activity for the left internal and external oblique to be during the windup phase of the tennis serve.

The majority of the energy being exerted in the early cocking phase is occurring at the beginning of the kinetic chain in the lower extremity and core. In the upper extremity, the main goal of this phase is to abduct and horizontally abduct the arm to the proper throwing position. As seen from Figure 11 the shoulder moves from about 40° of abduction to 83° by front foot contact. This movement is mainly accomplished by the upward movement of the scapula produced by a concentric contraction of the seratus anterior and the anterior deltoid. As seen from Figures 15 and 18, a minimal amount of contraction occurs from the seratus anterior (18 ± 14%) and the anterior deltoid (13 ± 11%). However, compared to other shoulder movers, these muscles seem to be the most active during this phase. The shoulder during this phase also undergoes horizontal abduction as well as staying slightly externally rotated (Figure 11). The shoulder reaches 14 ±7° of horizontal adduction as well as 15 ± 7 degrees of external rotation at the instant of front foot contact. The amount of external rotation is much different than that which has previously been published in football (90° and 47°) while the amount of horizontal abduction is similar (7° and -1°) (Table 11). These differences in external rotation values were previously discussed in the section comparing the kinematics and kinetics to previous results.

A major concern for pitchers is the tearing of the labrum. Interestingly, there is a low incident of labral tears in quarterbacks. One cause of labral tears is from the translation and subluxation of the humeral head in the anterior direction during the cocking phase. This results in entrapment of the labrum between the humeral head the glenoid rim (J. R. Andrews et al., 1991). Thus, proper anterior forces are required for a successful throw. An anterior shear force, as seen in Table 9, of 310 to 380 N is needed during the arm cocking phase (Feltner and Dapena, 1986, Werner, Fleisig et al. 1993, Fleisig, Andrews et al. 1995, Fleisig, Escamilla et al. 1996). The current study shows an anterior force in the shoulder during the phase to be 313 ± 38 N, which falls on the lower end of the values reported in the pitching literature, providing further evidence of a lower risk of labral tears.

The early cocking phase also produced minimal amounts of movement from the elbow of the throwing arm. A minimally active biceps brachii (14 ± 18%) eccentrically contracts during this phase to stabilize the elbow and resists the force from the ball and gravity to cause extension. One important measure in terms of injury in the baseball pitcher is maintaining a certain amount of varus torque in order to not cause injury due to the valgus torque at the elbow. Fleisig et al indicated that in order to maintain a certain varus torque of around 51Nm, the elbow should aim to be flexed at 95° (G. S. Fleisig et al., 1996). Interestingly, in the current study the elbow was able to remain in a flexed position of 97 ± 4°, however this resulted in amount of varus torque of 27 ± 5 Nm, which is much lower than the amounts normally seen in the pitching literature. This decrease in the amount of varus torque seen during the football pass could be critical for the lack of UCL injuries and subsequent “Tommy John” surgeries seen in quarterbacks.

Late Cocking Phase

The late cocking phase starts at front foot contact and continues until maximum shoulder external rotation. During the late cocking phase, the force produced from the push off of the back leg has already caused the start of the kinetic chain of events. In an effective throwing motion the kinetic energy generated from the lower extremity and trunk is transferred to the upper extremity (R. F. Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998). As demonstrated from this study, all the lower extremity muscles produce a moderate muscle activity except the left vastus lateralis. The left vastus lateralis produces a maximally active contraction (77 ± 57%) to stabilize the left leg at rear foot contact through to push-off. The stride leg extension is important for the transfer of energy. The continued extension at the knee after front foot contact enables the energy to be transferred to the trunk and not travel through the stride leg to the ground. These muscles were described above as being the Group 4b muscles of the football throw. Group 4b muscles are the leg stabilizers and produce the greatest activity during the late cocking phase. The muscles included in this group are the left vastus lateralis and left gluteus maximus. These muscles help stabilize the body once front foot contact occurs. The contractions produced from these muscles allow the body above to rotate above it.

As mentioned in the introduction, the stride leg is responsible for transmitting the energy up the body to maximize power output (MacWilliams et al., 1998). Thus, it has been hypothesized that being able to have a properly flexed knee at foot contact allows for proper rotation of the upper torso (Matsuo et al., 2001). As seen from the Table 3, the normal amount of flexion seen at this instance is between 38° and 51° in baseball pitching (Dun et al., 2007; C. S. Fleisig et al., 1996; G. S. Fleisig et al., 2006). The current study showed as slightly more amount of knee flexion of 60 ± 6°, possibly due to the football throw occurring on level ground and not a baseball mound.

The next chain in the kinetic chain is the trunk. In this phase the trunk begins to angularly accelerate. The left trunk muscles produce similarly with all but the left internal oblique producing moderately active contraction. These muscles were described above as being the Group 3 muscles of the throw. Group 3 muscles are the core accelerators. Figure 14 shows that during this phase, the thorax of the thrower has already begun to rotate. These muscles concentrically contract to be able to produce large forces to transfer up the kinetic chain for the shoulder and arm to produce large forces during the acceleration phase. As the prime mover of the trunk twisting contraction, the internal oblique produced a maximal contraction (80 ± 40%). All these contractions allow for the upper torso angular velocity to reach 756 ± 150 degrees per second about the long vertical axis during this phase in the direction of the throw. Thus, creating the energy to transfer to shoulder.

Although the torso is rotating at high velocities, the throwing arm lags behind. This causes a large amount of activity in some shoulder musculature to keep the shoulder moving with the trunk as well as to prevent excess shoulder external rotation (R. F. Escamilla & Andrews, 2009). In addition, the shoulder accelerators, such as the pectoralis major, latissimus dorsi, and anterior deltoid are also experiencing a stretch in this phase that will later help produce the large internal rotation in the shoulder. These muscles are moderately active during this phase with activity levels of 62 ± 39, 33 ± 6, and 49 ± 22 respectively.

As seen from Figure 11 the shoulder experiences a rapid external rotation during the late cocking phase until it reaches a maximum of 117 ± 4 degrees at the end of the late cocking phase. This value is much smaller than has previously been reported in both the football and baseball literature as previously discussed. During this rapid external rotation, an internal rotation torque of 70 ± 4 Nm is produced to resist the movement. In the current study the latissimus dorsi is moderately active (33±6%) in this phase while the infraspinatus is minimally active (17 ± 2%). The infraspinatus muscles, as a part of the rotator cuff muscles, generates a posterior force which help resist the anterior force of 313 ± 38 N. This helps to unload the glenohumeral ligament as well as allow for external rotation range of motion (Glenn S Fleisig et al., 1995). The reported activity level of the infraspinatus could be low due to this muscle activity being measured with surface electrodes instead of the indwelling electrodes commonly seen with the rotator cuff muscles, including the infraspinatus (Kelly et al., 2002). The latissimus dorsi is experiencing an eccentric contraction as to stretch the muscle and prepare for the next phase when it will work as one of the prime internal rotators.

DioGiovine et al found that the high muscle activity of the serratus anterior enabled the abduction to occur as it stabilized and protracted the shoulder (DiGiovine et al., 1992). The current study shows a continued abduction of the shoulder throughout this phase. However, a substantially lesser amount of activity of the serratus anterior was found in the current study. The current study showed a minimally active muscle (29 ± 9%) whereas DioGiovine determined an almost maximally active muscle (69 ± 32%). This smaller amount demonstrated in the current study could be due to the shoulder already abducting throughout the early cocking phase as well. This continual contraction could have caused smaller amounts of activity as opposed to a quick ascent of the arm.

The throwing shoulder additionally remains in a relatively constant state of horizontal adduction. The maximum horizontal adduction during this phase of 29 ± 18° is relatively stable compared to the angle of 15 ± 7° demonstrated at the end of the early cocking phase. However, this increase is the beginning of the steady increase in horizontal adduction seen throughout the remainder of the throw. This motion is due to a horizontal adduction torque being produced that reaches a maximum value of 31 ± 7 Nm. Moderate activity from the pectoralis major (62 ± 39%) as well as the anterior deltoid (49 ±22 %) is needed in order to horizontally adduct the shoulder, which is similar to that found in both the football and baseball literature (DiGiovine et al., 1992; Kelly et al., 2002).

As seen in Figure 12 the elbow remains in a relatively constant state of flexion throughout this phase, reaching a maximum of 114 ±7°. However, the elbow experiences a large medial force of 234 N and varus torque of 27 ± 5 Nm. During this phase, the triceps brachii (43 ±12%) produce a moderate amount of activity as compared to the biceps brachii. The triceps brachii have been shown to help control the rate of elbow flexion during the phase (R. F. Escamilla et al., 1998). In addition, the triceps brachii are also needed to initiate the elbow extension that starts to occur towards the end of the phase.

Acceleration Phase

The acceleration phases is defined as starting at maximum external rotation and continuing until ball release. During the acceleration phase, the kinetic chain had transferred the energy from the thorax to the shoulder. In order for the energy to transfer, the extension at the stride knee as well as the rotations that were seen at trunk need to continue but at a slower rate. The largest activity from these muscles was seen by a moderate activity in the left gluteus maximus (35 ± 13%). This moderate activity is needed in order to stabilize the hip from the continual twisting motion occurring above at the trunk. This decrease in energy in the hip and trunk allows the energy to be efficiently transferred.

The main movement of the shoulder during this phase is internal rotation and horizontal adduction. The movements of these motions are very quick with internal rotation angular velocity reported in the literature as being 6500 degrees per second (R. F. Escamilla et al., 2007). This phase has also been reported to occur only in 30-50 msec (R. F. Escamilla et al., 1998; Pappas, Zawacki, & Sullivan, 1985). Thus, high muscle activity was seen in the glenohumeral internal rotators and horizontal adductors. The current study found a moderate activity for the pectoralis major while a maximal activity for the latissimus dorsi. These values were also similar to those value reported in both football and baseball studies (DiGiovine et al., 1992; Kelly et al., 2002). These muscles were characterized earlier as being Group 2 muscles. Group 2 muscles of the current study are similar to the group 2 muscles described by Kelly et al (Kelly et al., 2002). The muscles in the current study included in this group are the triceps brachii, anterior deltoid, latissiumus dorsi, and pectoralis major. These muscles are concentrically contracting to accelerate the arm through the throw.

In order for the shoulder to be able to contract and rotate internally as well as horizontally adduct, the shoulder maintain a level of abduction. In order to keep the shoulder abducted, the deltoids and serratus anterior contract eccentrically. The minimal activity seen from the anterior and posterior deltoids are similar to that found in the football and baseball literature (DiGiovine et al., 1992; Kelly et al., 2002). In addition a moderate activity was seen for the serratus anterior during this phase.

At maximal external rotation, the elbow experiences a rapid extension until ball release, reaching an angle of 63 ± 22°. In order to produce such a rapid extension velocity of 2043 ± 172°/s a moderate activity contraction of the triceps brachii was produced (44 ± 11%). This was similar to DiGiovine et al in that the acceleration phase produced the largest activity (DiGiovine et al., 1992). However, other studies such as Werner et al (Werner et al., 1993) showed relatively low amounts of triceps activity. These results demonstrate two different possible functions of the triceps of the triceps during this phase. A study by Roberts et al (Roberts, 1971) showed that subjects with paralyzed triceps could still achieve ball velocities of greater than 80% normal. This extension of the forearm could just be caused by an abrupt stop of the humerus with very little amount of triceps activity needed to concentrically contract to extend the forearm. In the current study, this additional activity of the triceps could be due to the additional mass of the object being thrown. Thus, maybe during this phase, the main function of the triceps is to help stabilize the shoulder by the triceps longhead (R. F. Escamilla & Andrews, 2009).

Deceleration/Follow Through Phase

For the purposes of this section, the deceleration phase and follow through phase will be grouped together. This is due to these two phases being grouped together in the electromyographic results. These phases were grouped together in these results to reproduce the results seen in Kelly et al (Kelly et al., 2002). The deceleration phase begins at ball release and for the purpose of this section of the discussion the end of the follow through phase is at the end of the throw.

During the deceleration phase, the main priority of the most of the joints, especially the shoulder, is to dissipate the excess kinetic energy that is not transferred to the ball. This phase has the potential to produce large loads on the shoulder and any pathokinematics at this phase can result in injury. As mentioned in the early cocking phase, tears of the labrum are of great concern for pitchers. During this phase, a proper amount of posterior force is needed and has been characterized in pitcher to be between 240 and 400 N (Feltner and Dapena, 1986, Werner, Fleisig et al. 1993, Fleisig, Andrews et al. 1995, Fleisig, Escamilla et al. 1996). In this study, the shoulder is seen to be continuing to internally rotate as well as horizontally adducting during this phase (Figures 11). These motions produce a shoulder posterior force as high as 299 ± 37N and a shoulder horizontal abduction torque of 103 ± 28 Nm further indicating a lack of concern for labral tears. However, the posterior musculature should be the most active in order to eccentrically contract to control the motion. Interestingly, as seen from the results, the infraspinatus and posterior deltoid were minimally active. This inability to produce forces in the posterior shoulder could due to these muscles eccentrically contracting during this phase, a type of muscle activity that is known to elicit smaller amounts of EMG. In addition, the limitations of the measurements of the MVIC could also have caused an inaccurate representation of muscle activity during this phase.

The most muscle activity seen was from the serratus anterior, which produced close to a moderate activity (28 ± 12%). This muscle, as seen in previous phase, has been used throughout much of the throw to stabilize the abduction of the shoulder as well as clamp the scapula to the thorax. However, as seen in Figure 2, the shoulder begins to slightly begin to adduct in this phase. Thus, this activity from this muscle can be attributed to an eccentric contraction to stabilize the shoulder while it starts to adduct due to the throw.

The last large motion seen in the deceleration phase is the elbow beginning to flex. As seen from this motion, the biceps brachii contract eccentrically, but only minimally. Contrarily, studies on baseball have found that the biceps becomes the most active during this phase (DiGiovine et al., 1992). These studies have discussed another such purpose of the biceps to help synergistically with the rotator cuff to resist the distraction of the glunohumeral joint.

Summary

This chapter was able to provide an in depth discussion of the movement of the body throughout all stages of the football throw. This chapter was able to provide a discussion on the similarities seen with the current study to the values already published in previous paper. It hypothesized why there were differences in some values reported and not in others. In addition, this chapter brought together kinematics, kinetics, and electromyography data from this study to provide interpretation of the whole mechanics used in the football throw and where pathologies might occur.

CHAPTER SIX

The purpose of this study was to provide a comprehensive analysis of the football throw. This analysis combined kinematics, kinetics, and muscle activity data to describe the throw. Chapter six will present a summary of the study as reported in the previous chapters. This will include a summary of the methods and results seen in the current study. In addition, this chapter will discuss potential future studies due to the results seen in this study.

Summary

A thorough understanding of the proper mechanics needed to successfully throw a football is needed for coaches to appropriately be able to teach the skill. However, a comprehensive study investigating all aspects of the football throw has been lacking in the literature. Thus, the purpose of this study was to investigate the kinematics, kinetics, and electromyography of the football throw as seen in collegiate quarterbacks.

For this study, three collegiate quarterbacks completed a testing session where 10 drop backs football throws were recorded. To evaluate the throw, the study used a multi-camera motion capture system to record movements of 72 anatomical landmarks. These landmarks could be used to calculate joint angles as well as velocities. In addition, force platforms were used in order to calculate kinematics occurring at the joints of interest. Lastly, a multi-channel Delsys EMG system could be used to determine muscle activity of 16 muscles involved in the throw. The muscles were evaluated for their onset and offset as well as their relative amount of activity during each phase of the throw.

The results of this study were able to give a breakdown in the types of mechanics needed in each of the phases of the throw. This study demonstrated that during the early cocking phase, most of the movement seen in the upper body occurs in the frontal plane to abduct the shoulder. During this phase, quarterbacks produced minimal amounts of varus torque in the elbow, indicating a minimal risk for UCL injuries in quarterbacks. During the late cocking phase, the shoulder holds a constant abduction angle and begins to externally rotate. The shoulder reaches a value of 117° of external rotation, much less than has previously been reported. During the acceleration phase, the shoulder rapidly internally rotates as well as horizontally adducts. Once the ball is released, the shoulder has to produce large forces and muscle activity to slow down the rotation. However, these subjects indicated inability to properly activate the posterior shoulder musculature, which could be a concern as the shoulder fatigues over a season. These results will be able to give coaches and players a tool for what to look for when evaluating the mechanics of an individual.

Future Research

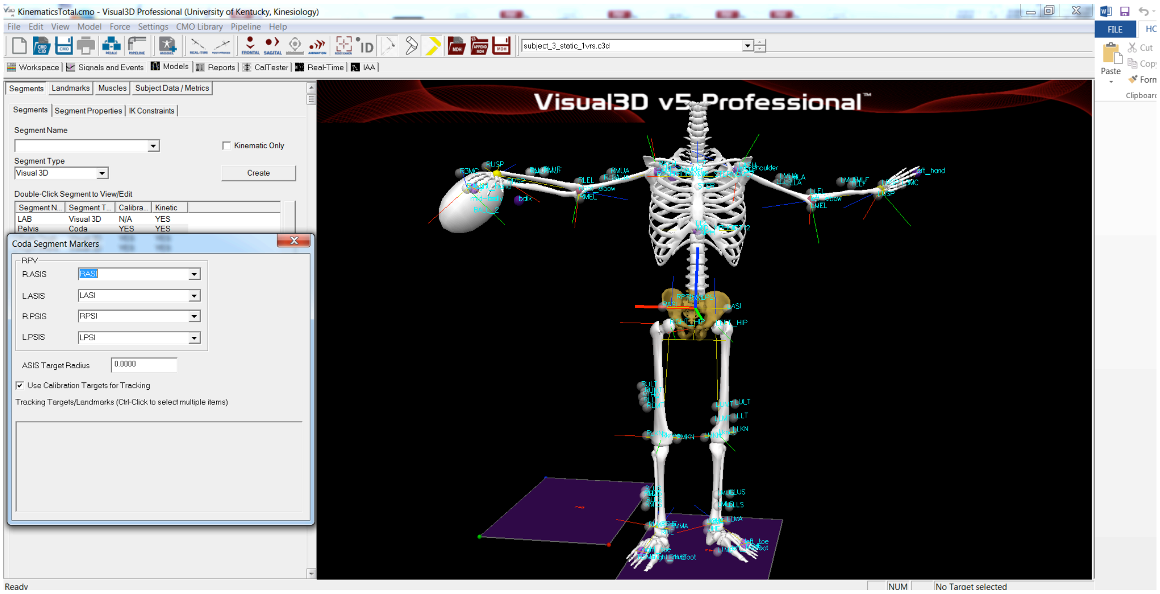
An additional study could be completed with the same protocol. As this study was limited by the amount of healthy quarterbacks available, additional study of more subjects are needed to get a true description of the mechanics. A potential next study could be to determine the effect of chronic fatigue over a whole football season. The current study has been demonstrated the resting and proper mechanics of the football throw with no fatigue. The most interesting question that follows is what happens to those mechanics when fatigue is introduced? Is there an increase in varus torque of the elbow and could this possibly be the key variable in biceps tendonitis seen in quarterbacks? Are the subjects able to start to produce proper muscle activity of the posterior shoulder during deceleration? Additionally, if these variables are the major concern for quarterbacks, can we provide an exercise protocol to help with these values? In order to complete this study, the same protocol could be used with each subject coming in once a month over the entire season. This could be able to help the coaches understand how to best deal with the load of the season in order to reduce fatigue as well as potential injury.

APPENDIX

A local coordinate system was calculated for each segment to allow transformation of segment marker coordinates to an anatomically relevant reference frame. The local coordinate system for all relevant segments will be defined here in the appendix. For all segments, the wiki page on Visual 3D was used to help define the segments (https://www.c-motion.com/v3dwiki/index.php/Main_Page). In each figure, the red axis denotes the X-axis, the blue the Z-axis, and the green the Y-axis.

Pelvis

The CODA pelvis refers to a pelvis segment model used by Charnwood Dynamics. The pelvis segment is defined using the anatomical locations of the left and right ASIS (Anterior Superior Iliac Spine) and the PSIS (Posterior Superior Iliac Spine). The origin of the pelvis segment was defined as the mid-point between the LASI and RASI markers. The X-axis was defined from the origin towards the RASI. The Z-axis was defined perpendicular to the (x-y) plane. Lastly, the Y-axis was then the cross product of the X-axis and Z-axis. Movement about the X axis is considered pelvic tilt, movement about the Y axis lateral tilt, and movement about the Z-axis pelvic rotation.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Segment Name:

☐ Kinematic Only

Segment Type: Visual 3D

Double-Click Segment to View/Edit

Segment N...	Segment T...	Calibra...	Kinetic
LAB	Visual 3D	N/A	YES
Pelvis	Coda	YES	YES

Coda Segment Markers

RPV

R.ASIS: RASI

L.ASIS: LASI

R.PSIS: RPSI

L.PSIS: LPSI

ASIS Target Radius: 0.0000

☑ Use Calibration Targets for Tracking

Tracking Targets/Landmarks (Ctrl-Click to select multiple items)

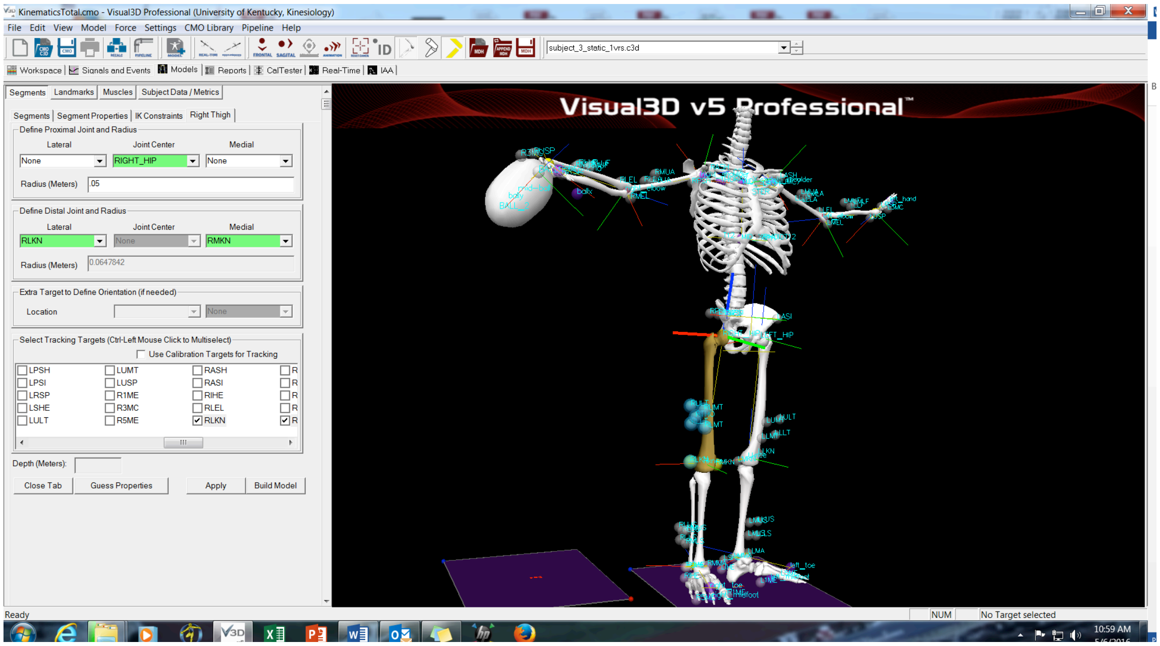
Ready

NUM

No Target selected

Upper Leg Segment

The endpoints used for establishing the upper leg segment were the hip center, lateral femoral condyle, and medial femoral condyle. Given that there are three border targets, the frontal plane was defined by the three targets. With three targets, Visual 3D creates a segment end at the midpoint between the medial and lateral femoral condyle. The Z-axis was then defined from the distal (Knee center) endpoint to the proximal endpoint (Hip Center). The local Y-axis for the upper leg shank was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers used for this segment were a cluster of four markers on the shank as well as the lateral knee marker. The movements about the X-axis are flexion/extension, Y-axis movements are abduction/adduction, and movements about the Z-axis are internal and external rotation.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Right Thigh

Define Proximal Joint and Radius

Lateral: None

Joint Center: RIGHT_HIP

Medial: None

Radius (Meters): .05

Define Distal Joint and Radius

Lateral: RLKN

Joint Center: None

Medial: RMKN

Radius (Meters): 0.0647842

Extra Target to Define Orientation (if needed)

Location: None

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

☐ Use Calibration Targets for Tracking

☐ LPSH ☐ LUMT ☐ RASH ☐ R

☐ LPSI ☐ LUSP ☐ RASI ☐ R

☐ LRSP ☐ R1ME ☐ RIHE ☐ R

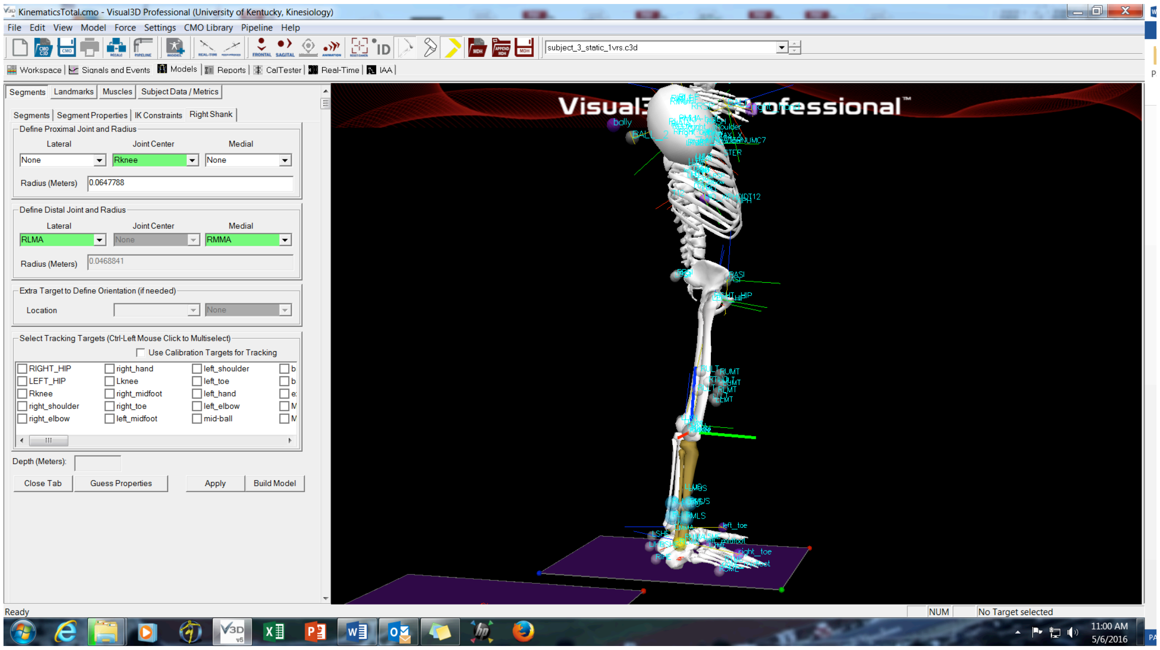
☐ LSHE ☐ R3MC ☐ RLEL ☐ R

☐ LULT ☐ R5ME ☑ RLKN ☑ R

Depth (Meters):

Lower Leg Segment

The endpoints used for establishing the lower leg segment were the knee center, lateral malleolus, and medial malleolus. Given that there are three border targets, the frontal plane was defined by the three targets. With three targets, Visual 3D creates a segment end at the midpoint between the medial and lateral malleolus. The Z-axis was then defined from the distal (Ankle center) endpoint to the proximal endpoint (Knee Center). The local Y-axis for the lower leg was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers used for this segment were a cluster of three markers on the lower shank as well as the lateral malleolus marker. The movements about the X-axis are flexion/extension, Y-axis movements are abduction/adduction, and movements about the Z-axis are internal and external rotations.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Right Shank

Define Proximal Joint and Radius

Lateral: None

Joint Center: Rknee

Medial: None

Radius (Meters): 0.0647788

Define Distal Joint and Radius

Lateral: RLMA

Joint Center: None

Medial: RMMA

Radius (Meters): 0.0468841

Extra Target to Define Orientation (if needed)

Location: None

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

☐ Use Calibration Targets for Tracking

☐ RIGHT_HIP ☐ right_hand ☐ left_shoulder
☐ LEFT_HIP ☐ Lknee ☐ left_toe
☐ Rknee ☐ right_midfoot ☐ left_hand
☐ right_shoulder ☐ right_toe ☐ left_elbow
☐ right_elbow ☐ left_midfoot ☐ mid-ball

Depth (Meters):

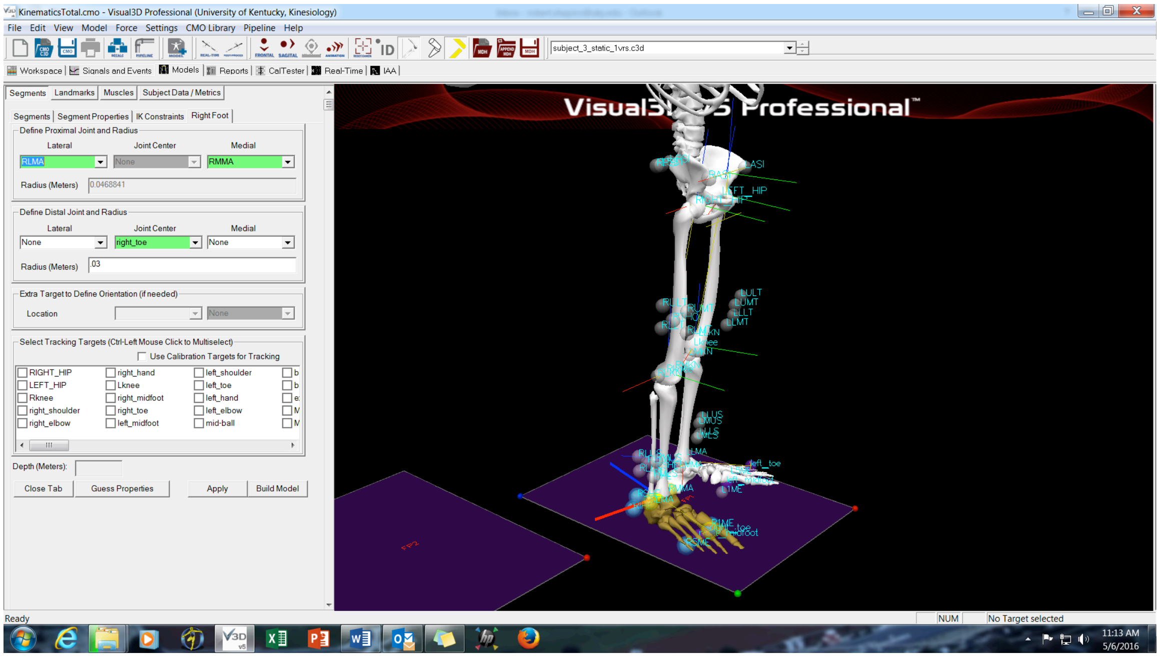
subject_3_static_1vrs.c3d

No Target selected

11:00 AM
5/6/2016

Foot Segment

The endpoints used for establishing the foot segment were the toe, lateral malleolus, and medial malleolus. Given that there are three border targets, the frontal plane was defined by the three targets. With three targets, Visual 3D creates a segment end at the midpoint between the medial and lateral malleolus. The Z-axis was then defined from the distal (Toe) endpoint to the proximal endpoint (Ankle Center). The local Y-axis for the foot was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers used for this segment were a cluster of two markers on the heel of the foot as well as the lateral maleolus marker and toe maker. The movements about the X-axis are dorsi-flexion/plantar-flexion, Y-axis movements are eversion/inversion, and movements about the Z-axis are plane abduction and adduction.



Define Proximal Joint and Radius
Lateral: RLMA
Joint Center: None
Medial: RMMA
Radius (Meters): 0.0468841

Define Distal Joint and Radius
Lateral: None
Joint Center: right_toe
Medial: None
Radius (Meters): .03

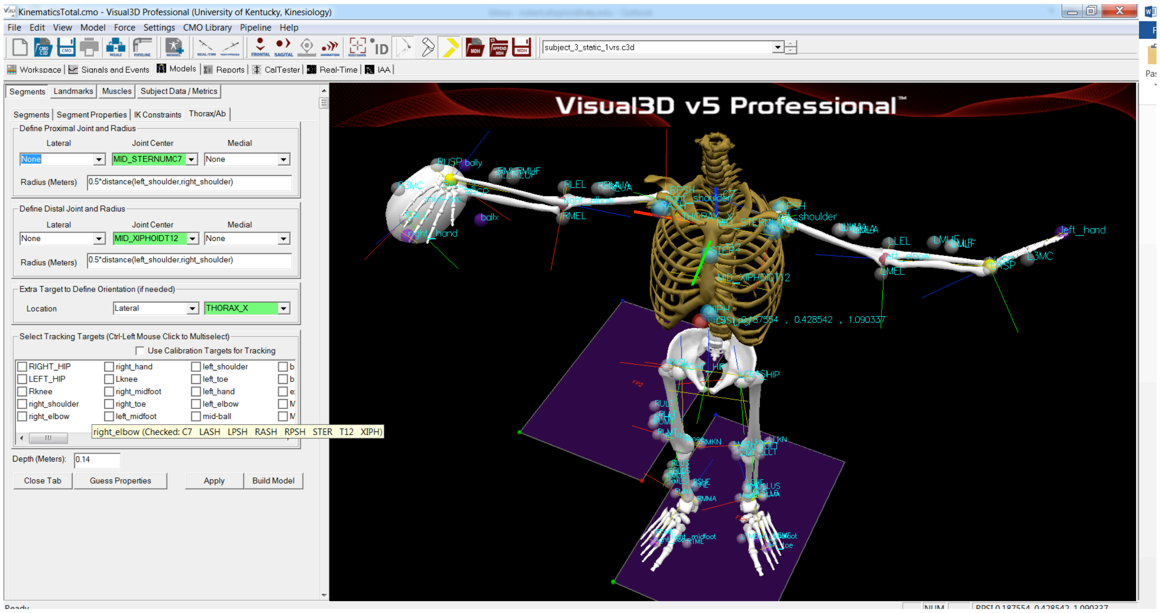
Extra Target to Define Orientation (if needed)
Location: None

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)
☐ Use Calibration Targets for Tracking
☐ RIGHT_HIP ☐ right_hand ☐ left_shoulder
☐ LEFT_HIP ☐ Lknee ☐ left_toe
☐ Rknee ☐ right_midfoot ☐ left_hand
☐ right_shoulder ☐ right_toe ☐ left_elbow
☐ right_elbow ☐ left_midfoot ☐ mid-ball

Depth (Meters):

Thorax

Three landmarks were created in order to model the thorax. The first was the mid sternum C7. This was created as a midpoint starting at the sternum and ending at the C7 marker. The second landmark was the mid xiphoid T12 landmark. This was created as the midpoint between the xiphoid process and the T12 marker. The last landmark created was the Thorax-X landmark. This was created similar to the sternum landmark with a starting point at the sternum and ending at C7. An additional lateral object was identified at the mid xiphoid T12 landmark. After these landmarks were created, the thorax was modeled as the Z-axis was then defined from the distal (xiphoid) endpoint to the proximal endpoint (sternum). The local Y-axis for the thorax was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers were the sternum, xyphoid process, C7, and T12 markers. The movements about the X-axis are flexion/extension, Y-axis movements are right/left lean, and movements about the Z-axis are thorax rotations.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

subject_3_static_1vrs.c3d

Define Proximal Joint and Radius

Lateral: None

Joint Center: MID_STERNUMC7

Medial: None

Radius (Meters): 0.5*distance(left_shoulder,right_shoulder)

Define Distal Joint and Radius

Lateral: None

Joint Center: MID_XIPHOIDT12

Medial: None

Radius (Meters): 0.5*distance(left_shoulder,right_shoulder)

Extra Target to Define Orientation (if needed)

Location: Lateral THORAX_X

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

☐ Use Calibration Targets for Tracking

☐ RIGHT_HIP ☐ right_hand ☐ left_shoulder

☐ LEFT_HIP ☐ Lknee ☐ left_toe

☐ Rknee ☐ right_midfoot ☐ left_hand

☐ right_shoulder ☐ right_toe ☐ left_elbow

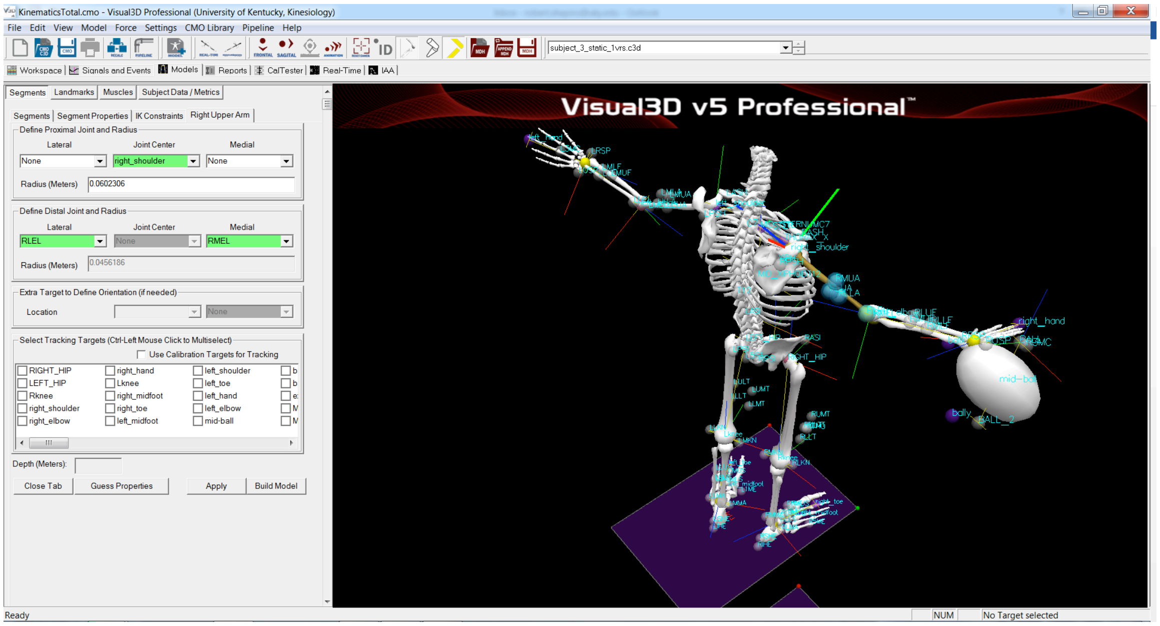
☐ right_elbow ☐ left_midfoot ☐ mid-ball

right_elbow (Checked: C7 LASH LPSH RASH RPSH STER T12 XIPH)

Depth (Meters): 0.14

Upper Arm Segment

The endpoints used for establishing the upper arm segment were the shoulder center, lateral elbow, and medial elbow. Given that there are three border targets, the frontal plane was defined by the three targets. With three targets, Visual 3D creates a segment end at the midpoint between the medial and lateral elbow markers. The Z-axis was then defined from the distal (elbow center) endpoint to the proximal endpoint (shoulder center). The local Y-axis for the upper arm was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers used for this segment were a cluster of four markers on the upper arm as well as the lateral elbow marker. The movements about the X-axis are flexion/extension, Y-axis movements are abduction/adduction, and movements about the Z-axis are internal and external rotations.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Right Upper Arm

Define Proximal Joint and Radius

Lateral: None

Joint Center: right_shoulder

Medial: None

Radius (Meters): 0.0602306

Define Distal Joint and Radius

Lateral: RLEL

Joint Center: None

Medial: RMEL

Radius (Meters): 0.0456186

Extra Target to Define Orientation (if needed)

Location: None

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

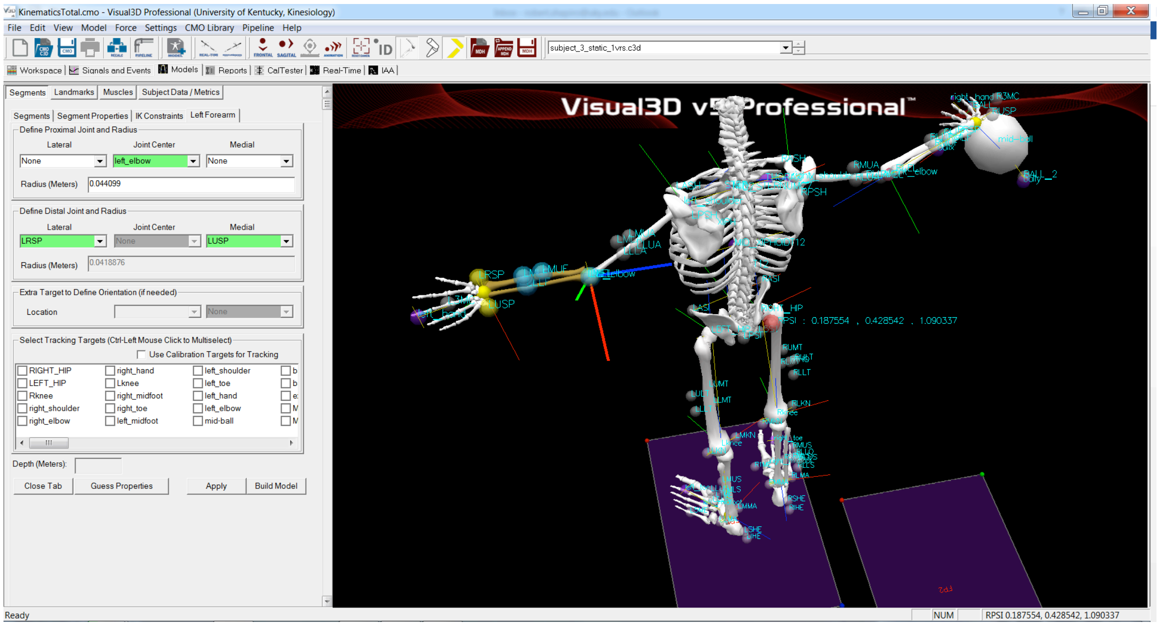
☐ Use Calibration Targets for Tracking

Depth (Meters):

subject_3_static_1vrs.c3d

Forearm Segment

The endpoints used for establishing the forearm segment were the elbow center, lateral wrist, and medial wrist. Given that there are three border targets, the frontal plane was defined by the three targets. With three targets, Visual 3D creates a segment end at the midpoint between the medial and lateral wrist markers. The Z-axis was then defined from the distal (wrist center) endpoint to the proximal endpoint (elbow center). The local Y-axis for the forearm was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers used for this segment were a cluster of three markers on the forearm arm as well as the lateral wrist marker. The movements about the X-axis are flexion/extension and the Z-axis are pronation and supination.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Define Proximal Joint and Radius

Lateral	Joint Center	Medial
None	left_elbow	None

Radius (Meters) 0.044099

Define Distal Joint and Radius

Lateral	Joint Center	Medial
LRSP	None	LUSP

Radius (Meters) 0.0418876

Extra Target to Define Orientation (if needed)

Location None

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

☐ Use Calibration Targets for Tracking

Depth (Meters):

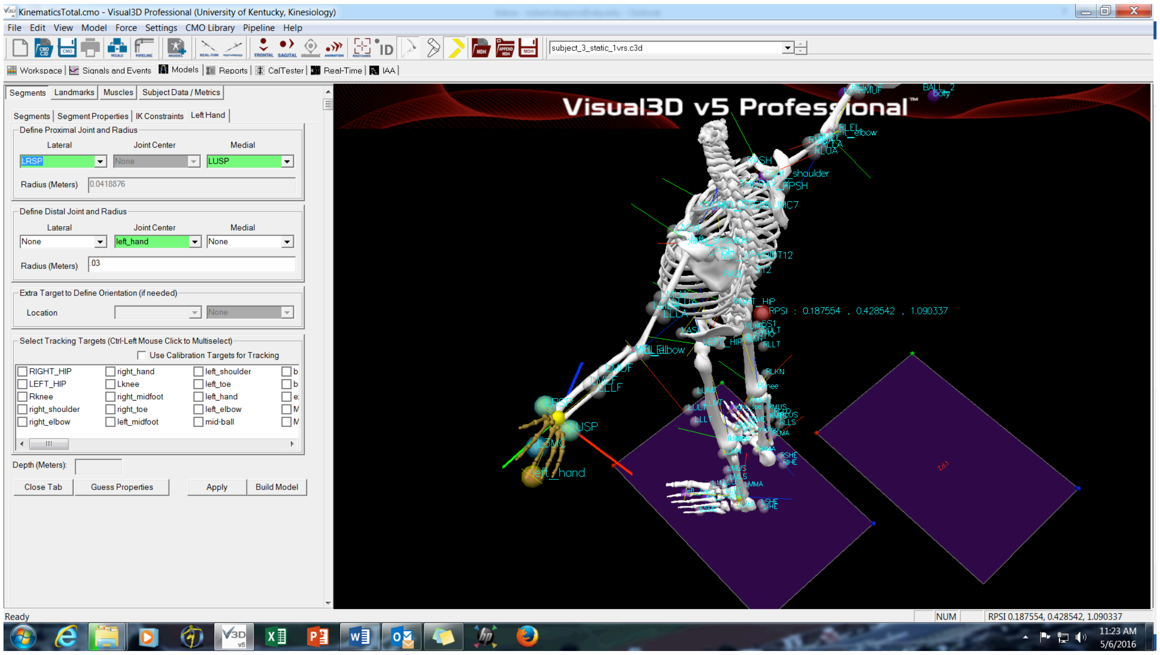
RPSI : 0.187554 , 0.428542 , 1.090337

Ready

RPSI 0.187554, 0.428542, 1.090337

Hand Segment

The endpoints used for establishing the hand segment were the hand marker, lateral wrist, and medial wrist. Given that there are three border targets, the frontal plane was defined by the three targets. With three targets, Visual 3D creates a segment end at the midpoint between the medial and lateral wrist. The Z-axis was then defined from the distal (hand) endpoint to the proximal endpoint (wrist Center). The local Y-axis for the hand was defined projecting forward in the anterior posterior direction. The local X-axis was then calculated perpendicular to the y-z plane using the right hand rule. The tracking markers used for this segment were the medial and lateral wrist markers as well as the marker on the hand. The movements about the X-axis are flexion/extension and Y-axis movements are ulnar/radial deviation.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Define Proximal Joint and Radius

Lateral	Joint Center	Medial
LRSP	None	LUSP

Radius (Meters): 0.0418876

Define Distal Joint and Radius

Lateral	Joint Center	Medial
None	left_hand	None

Radius (Meters): .03

Extra Target to Define Orientation (if needed)

Location: None

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

☐ Use Calibration Targets for Tracking

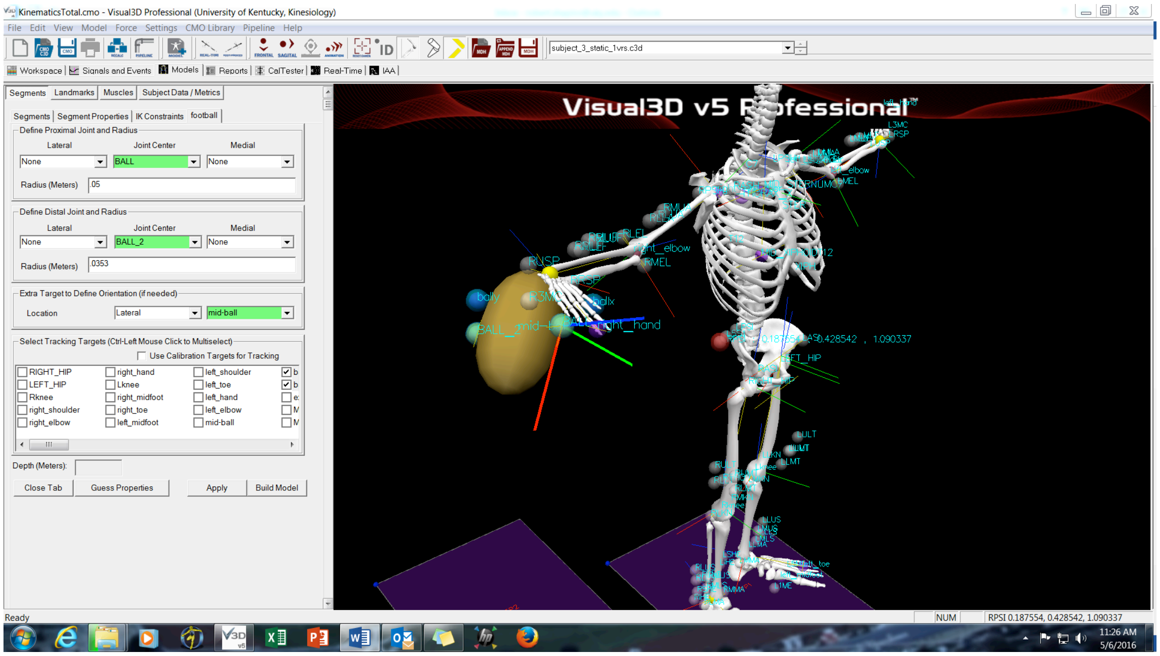
☐ RIGHT_HIP ☐ right_hand ☐ left_shoulder
☐ LEFT_HIP ☐ Lknee ☐ left_toe
☐ Rknee ☐ right_midfoot ☐ left_hand
☐ right_shoulder ☐ right_toe ☐ left_elbow
☐ right_elbow ☐ left_midfoot ☐ mid-ball

Depth (Meters):

RPSI : 0.187554 , 0.428542 , 1.090337

Ball Segment

The ball was defined by the placement of reflective tape on both ends of the ball.



KinematicsTotal.cmo - Visual3D Professional (University of Kentucky, Kinesiology)

Define Proximal Joint and Radius

Lateral: None
Joint Center: BALL
Medial: None
Radius (Meters): .05

Define Distal Joint and Radius

Lateral: None
Joint Center: BALL_2
Medial: None
Radius (Meters): .0353

Extra Target to Define Orientation (if needed)

Location: Lateral, mid-ball

Select Tracking Targets (Ctrl-Left Mouse Click to Multiselect)

☐ Use Calibration Targets for Tracking

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VITA

NAME OF FELLOWSHIP APPLICANT Kyle R. Bohnert	POSITION TITLE Graduate Student
eRA COMMONS USER NAME (credential, e.g., agency login) krbohn02	

EDUCATION/TRAINING (Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
Hanover College, Hanover, IN	BA	2008-2012	Exercise Science & Psychology
University of Kentucky, Lexington, KY	MS (Expected)	2012-2014	Biomechanics
University of Louisville, Louisville, KY	MS (Expected)	2014-Pres	Anatomy & Neurobiology
University of Louisville, Louisville, KY	Ph.D. (Expected)	2014-Pres	Anatomy & Neurobiology

B. Positions and Honors

ACTIVITY/OCCUPATION	BEGINNING DATE (mm/yy)	ENDING DATE (mm/yy)	FIELD	INSTITUTION/COMPANY	SUPERVISOR/ EMPLOYER
Graduate Student	08/12	05/14	Kinesiology and Health Promotion	University of Kentucky	Dr. Robert Shaprio University of Louisville
Teaching Assistant	08/12	05/13	Kinesiology Wellness Classes	University of Kentucky	University of Kentucky
Teaching Assistant	05/13	05/14	Biomechanics Laboratory	University of Kentucky	University of Kentucky
Graduate Student	08/14	Pres	Anatomical Sciences and Neurobiology	University of Louisville	Dr. Ashok Kumar University of Louisville
Teaching Assistant	04/16	05/16	Gross Neuroanatomy Laboratory	University of Louisville	University of Louisville

Academic and Professional Honors

- Graduate Fellowship Awarded, University of Louisville, Aug 2011-2013

C. Scholastic Performance

GRE Scores: Verbal 155, Quantitative 155, Writing 4.0
Graduate GPA: 3.738