Influence of the Lumbopelvic-hip Complex on Upper Extremity Kinetics in Baseball Pitching

by

Portia Terrilyn Williams

A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
August 3, 2019

Keywords: lumbopelvic-hip complex, baseball pitching, upper extremity, single leg squat

Approved by

Gretchen D. Oliver, Chair, Professor of Kinesiology
Wendi H. Weimar, Professor of Kinesiology
Danielle Wadsworth, Associate Professor of Kinesiology
Octavia L. Tripp, Associate Professor of Science Education

Abstract

The ability of the upper extremity to function efficiently, depends on the strength and stability provided by the lower extremity and lumbopelvic-hip complex (LPHC), however the vast majority of overhead throwing literature focuses on the upper extremity. To the author's knowledge, data available investigating the influence of functional LPHC stability in baseball pitching is limited. It was the purpose of this study to investigate the correlation of LPHC stability via the single leg squat (SLS) to shoulder and elbow kinetics, and ball control (velocity and spin) during the fastball baseball pitch. Twenty-five right handed male baseball athletes volunteered to participate (17.33 ± 3.05 years; 182.42 ± 9.18 cm; 78.62 ± 15.57 kg). Results revealed no relationship between SLS performance (degree of knee valgus) and shoulder kinetics. No relationship between SLS performance and elbow kinetics. There was no relationship between SLS performance and ball speed; and no relationship between SLS performance on the stance leg and ball spin. These findings are valuable to aid clinicians during the evaluating process to identify those persons whom may be at risk for upper extremity injuries. Future studies should consider examining knee and trunk kinematics when performing a single leg squat in other planes to include individuals with upper extremity dysfunctions as well as women baseball pitchers. Furthermore, establishing LPHC parameters for the single leg squat.would aid in continuity when evaluating patients.

Acknowledgements

Stay ten toes down and never fold, it's not on you it's within, and that can't be taken away!!
First giving honor to God because without him, there is no me.

This journey would not be possible without the help of my family and the countless hours of my complaining and allowing me to practice my presentations on them, even though they had no idea what I was talking about. Merceda Williams (I love you MOM!!) and Carolyn Johnson (G'ma)…prayer warriors.

Dr. Sarah Price, words cannot express my gratitude for pushing me out of my comfort zone in pursuit of this degree. As a mentor, colleague and always friend….many thanks!

I would like to begin with thanking the Auburn University professors that made this all possible: Dr. Gretchen Oliver for allowing me to be a part of the Sports Medicine and Movement Lab and achieving my first publication. Dr. Weimar thank you for taking a chance on this #blackexcellance in the making an individual whom was frustrated working countless hours knowing her time spent was worth more. Dr. Jared Russell, for trusting my judgements to be coordinator of the Future Scholars Summer Research Bridge Program and always telling me to "keep it pushing" or "you'll be alright." Dr. Christopher Wilburn, thank you for leading the way. Dr. Jamie Roper, for your spirit, you are an angel in disguise. Dr. Mary Rudisill, you're the best!! Continued peace and blessing your way.

To my friends for understanding, I cannot hang out this weekend and allowing me to call at odd hours to just to talk it through…thank you!

To the members of the Sports Medicine & Movement Lab: Jeff Barfield, Sarah Gascon, Jessica Downs, Kyle Wasserberger, Kenzie Friesen, Kevin Giordano, Regan Shaw, Abby Brittain… for your hours and dedication to collecting the data and being there even when participants did not show...thank you!

To the members of the Sport Biomechanics Lab: Brandi Decoux & Nick Moore thank you!

To my committee: Dr. Gretchen Oliver, Dr. Wendi Weimar, Dr. Danielle Wadsworth, Dr. Octavia Tripp and Dr. Melody Russell…thank you!

Table of Contents

List of Tables

List of Figures

List of Abbreviations

A/P	Anterior/Posterior
AB/ADD	Abduction/Adduction
Accel	Acceleration
BR	Ball release
BS	Ball spin
D/C	Deceleration/Compression
Decel	Deceleration
DEG	Degrees
FC	Foot contact
LPHC	Lumbopelvic-hip complex
MER	Maximum external rotation
MPH	Miles per hour
MUCL	Medial ulna collateral ligament
SLS	Single leg squat
SIG	Significance
UCL	Ulna collateral ligament

List of Symbols

N	Participant Sample
N	Newton
°	Degrees
R, r	Right
L, l	Left
α3	Skewness
α4	Kurtosis
ρ	Correlation Coefficient (Spearman rho)
p	Alpha Level of Significance
SEskew	Standard Error of Skewness
SEkurt	Standard Error of Kurtosis
b	Unstandardized Regression Coefficient
β	Standardized Regression Coefficient

CHAPTER 1

Introduction

The overhead throwing motion is complex and involves multiple systems of the body working to ultimately achieve the greatest ball velocity and accuracy (Chu, Jayabalan, Kibler, & Press, 2016; Fleisig, Barrentine, Escamilla, & Andrews, 1996a; W.B. Kibler, 1998). This multifaceted movement requires coordination, flexibility, and strength of both the lower and upper extremity for proper execution (Chu et al., 2016; Fleisig et al., 1996a; Putnam, 1993; Sauers, Huxel Bliven, Johnson, Falsone, & Walters, 2014; Seroyer et al., 2010). An overhead throwing motion that has gained popularity in research is the baseball pitch. With baseball now being a year-round activity; increases in pitching related injuries, specifically to the shoulder and elbow has increased to the point that the USA Baseball Medical & Safety Advisory Committee has recognized the need to improve our understanding of factors associated with these type of injuries (Kerut, Kerut, Fleisig, & Andrews, 2008). When examining the intricacy of the upper extremity during dynamic movements, an understanding of the glenohumeral (shoulder) and humeralulnar (elbow) joints is essential. The glenohumeral joint, or shoulder (that will be used from this point forward), is a ball and socket joint comprised of the humerus, scapula, and clavicle. The musculature about the shoulder can be further divided into the categories of intrinsic, extrinsic and scapula stabilizing (Kibler, 1998). The intrinsic group of shoulder musculature is comprised of the four muscles of the rotator cuff, while the extrinsic muscle group includes the deltoid, biceps and triceps muscles, the scapula stabilizing musculature includes the trapezius muscle group, rhomboid muscle group, levator scapulae, serratus anterior, and pectoralis minor. In addition to the shoulder and elbow joints, the scapula serves as a stable base for all shoulder movements and is essential for maintaining not only stability, but also effective and efficient mobility for upper extremity function (Kibler, 1998). Often, injuries sustained in dynamic overhead activities are overuse in nature and are the result of some type of scapular dysfunction. Along with the shoulder, the elbow is also of interest when examining overhead activities. The elbow connects the upper arm (humerus) to the forearm and is considered a hinge and pivot joint, which allows for flexion, extension, and rotation of the forearm. Elbow injuries, as a result of ballistic overhead activities, are often ligamentous and isolated to the ulnar collateral ligament (UCL). Formally referred to as the medial ulna collateral ligament, it is comprised of an anterior bundle, posterior bundle and a transverse ligament and these ligamentous bundles provide stability to the elbow. For overhead throwers, due to its high susceptibility to great forces during the baseball pitch, the anterior bundle of the UCL, which provides valgus stability to the elbow, is often injured leading to UCL injury (Chu et al., 2016; W.B. Kibler, Wilkes, & Sciascia, 2013; Labott, Aibinder, Dines, & Camp, 2018). While the UCL injury is often the result of the high velocity and associated forces, the rest of the body is responsible for developing those high velocities and should be considered in investigations of UCL injuries.

The total body acts as a kinetic chain to transfer energy from the lower to the upper extremity for dynamic overhead movements, hence understanding the anatomy and function of the lower extremity and its contributions in overhead movements is imperative (Chu et al., 2016; W.B. Kibler, 1998; W.B. Kibler et al., 2013). Just as the scapula is considered the stable base for shoulder movements, the pelvis is considered the stable base for trunk and scapular movements (McMullen & Uhl, 2000). Pelvic stability is often referred to as core stability or more appropriately lumbopelvic-hip complex (LPHC) stability. The LPHC includes all musculature that either originates or inserts on the lumbar spine, pelvis and femur; thus, is comprised of numerous muscles (Chu et al., 2016; W.B. Kibler, Press, & Sciascia, 2006; Sciascia, Thigpen, Namdari, & Baldwin, 2012). Based on the kinetic chain theory, the body is comprised of interdependent segments working synergistically for optimal movement (W. Ben Kibler, 1995; Putnam, 1993). In the examination of overhead movements, the critical link in the kinetic chain that allows for efficient energy transfer from the lower extremity to the upper extremity is the LPHC. The ultimate goal of overhead movements is to generate energy in the lower extremity and efficiently transfer the energy through the LPHC to the upper extremity so that the upper extremity can act as funnel to disperse the energy out the hand for performance (Kibler et al., 2006). For one to achieve the most efficient transfer of energy through the LPHC, proximal stability of the LPHC is needed in an attempt to produce distal mobility of the shoulder and elbow (Putnam, 1993). Thus, in dynamic overhead movements, a decrease in energy transfer requires the musculature of the upper extremity to create energy versus funnel energy (Chu et al., 2016). It has been reported that any dysfunction in the lower extremity and/or LPHC resulted in decreased energy transfer from the lower to the upper extremity (Kibler et al., 2006, 2013).

One specific overhead movement, that is continually examined, is the baseball pitch. The ballistic nature of the baseball pitch requires proper timing and the coordination of lower extremity, trunk, and upper extremity movements; thus, reiterating the need for an efficient kinetic chain with proximal stability for distal mobility (Chu et al., 2016; W.B. Kibler et al., 2013; Sauers et al., 2014; Seroyer et al., 2010). With the sport of baseball being one of the fastest growing sports in the world, (BSEMS, 2018; Melugin, Leafblad, Camp, & Conte, 2018) baseball pitchers are continually evaluated on not only performance, but also injury susceptibility

(BSEMS, 2018; Melugin et al., 2018; Woods, Spaniol, & Bonnette, 2008). Due to the dynamic repetitive nature of baseball pitching, any dysfunction in the kinetic chain predisposes one to injury susceptibility as well as influences one's performance outcomes (Burkhart, Morgan, & Kibler, 2003; Chu et al., 2016; W.B. Kibler et al., 2006; Sciascia et al., 2012; Wilk, Meister, Fleisig, & Andrews, 2000). In the examination of baseball injuries over the course of a season, the most prevalent injuries are to the shoulder and elbow (Fleisig & Andrews, 2012a; Lyman, Fleisig, & Andrews, 2002). Given the frequency of shoulder and elbow injuries, developing a proficient kinetic chain is imperative. Developing efficient energy production in the lower extremity, proximal stability of the LPHC, and effective energy transfer to the most distal segments of the hand and ball, is vital for improving performance and injury prevention (Chu et al., 2016; W.B. Kibler et al., 2006, 2013; Sauers et al., 2014; Seroyer et al., 2010).

With the known importance of LPHC stability, clinicians frequently utilize clinical tests to assess LPHC stability (Sauers et al., 2014). One of the more popular LPHC stability tests is the single leg squat (SLS) (Kibler et al., 2006; Sciascia et al., 2012). Used extensively for lower extremity dysfunction, the SLS is a controlled functional task resembling athletic activities (Claiborne, Armstrong, Gandhi, & Pincivero, 2006; Crossley, Zhang, Schache, Bryant, & Cowan, 2011; DiMattia, Livengood, Uhl, Mattacola, & Malone, 2005; Nishiwaki, Urabe, & Tanaka, 2006). The SLS assesses LPHC control through examination of trunk and knee deviations in the frontal and transverse planes and any weakness in these planes has been implicated as a potential kinetic chain deficit that could be displayed in the pitching cycle (Chu et al., 2016; Kageyama, Sugiyama, Takai, Kanehisa, & Maeda, 2014).

A pitcher's goal is to deliver a ball with the greatest velocity and precision. Elite pitchers have been known to achieve high ball velocities in excess of 90 miles per hour (40.23m/s). Over the course of a season, fastballs are most frequently thrown and evaluated by movement, velocity, and location (Higuchi, Morohoshi, Nagami, Nakata, & Kanosue, 2013). In the examination of ball movement, spin rate is the common performance measure. The manipulation of spin rate has been known to determine the direction and magnitude of the pitch ("Spin Rate," 2016). Variations within pitching performance, specifically spin rate, could not only make some pitchers more effective but also may have an enormous impact on the outcome of the game.

It has been hypothesized that alterations in lower extremity control during the pitching motion places increased stress across the shoulder and elbow joints which could potentially result in upper extremity injury in the overhead athlete (Fleisig & Andrews, 2012a; Fleisig et al., 1996a; Kantrowitz, Trofa, Woode, Ahmad, & Lynch, 2018). Previously, kinematic and kinetic variables have described multiple aspects of the baseball pitch, however, there are limited data available examining lower extremity stability and the influence on upper extremity force production in baseball pitching (Fleisig & Andrews, 2012a; Fleisig et al., 1996a; Kageyama et al., 2014; Lyman et al., 2002; Mullaney, McHugh, M Donofrio, & Nicholas, 2005; Worrell & Perrin, 1992). Pitching is a total body motion that incorporates the LPHC for improved performance, therefore efficient energy produced in the lower extremity and effective energy transfer to the most distal segments is vital (Chu et al., 2016; W.B. Kibler et al., 2006, 2013; Sauers et al., 2014; Seroyer et al., 2010).

Purpose

With the known importance of utilizing the proximal (lower extremity), LPHC, and distal (upper extremity) segments of the kinetic chain for efficient overhead movement, investigation into proximal stability for distal mobility is still needed. Therefore, it is the purpose of this study to investigate the correlation of LPHC stability, via the single leg squat (SLS), to shoulder and elbow kinetics, and ball control (velocity and spin) during the fastball baseball pitch.

Significance

Based on the kinetic chain theory proximal stability is needed for the achievement of distal mobility. In overhead throwing the kinetic chain theory has been addressed however, there is a lack of data examining functional LPHC stability and its relationship on upper extremity kinetics in overhead athletes. The results of this study will provide insight into the relationship of functional LPHC stability and baseball pitching.

Research Questions

RQ1: Is there a correlation between SLS performance (knee valgus) and shoulder kinetics (anterior/posterior, compressive/distraction, abduction/adduction forces) during baseball pitching?

RQ2: Is there a correlation between SLS performance (knee valgus) and elbow kinetics (anterior/posterior, compressive/distraction, valgus/varus forces) during baseball pitching?

RQ3: Is there a correlation between SLS performance (knee valgus) and ball speed during baseball pitching?

RQ4: Is there a correlation between SLS performance (knee valgus) and ball spin during baseball pitching?

Hypotheses

H01: Shoulder kinetics (anterior/posterior, compressive/distraction, abduction/adduction forces) will be negatively correlated with SLS performance (knee valgus) during the baseball pitch.

H02: Elbow kinetics (anterior/posterior, compressive/distraction, valgus/varus forces) will be negatively correlated with SLS performance (knee valgus) during the baseball pitch.

H03: Greater ball speed will be positively correlated with SLS performance (knee valgus).

H04: Greater ball spin will be positively correlated with SLS performance (knee valgus).

Limitations

Limitations of this study are below:

1. Participants will be from the same geographic region.
2. Variability of pitchers is usually high from muscle recruitment to usage of the kinetic chain and the types of pitches thrown depend on level of competition.
3. Baseball is a sport played on natural grass or artificial turf and clay surfaces, for this study, participants will be asked to wear tennis shoes for indoor testing.

Delimitations

Delimitations of this study are below:

1. All data collections will be executed in a controlled laboratory setting in the Auburn University Sports Medicine and Movement Laboratory.
2. Kinetic data will be collected using a tethered electromagnetic tracking system.
3. Ball velocity will be measured with a ball flight analytics monitor.
4. Ball spin will be measured with a ball flight analytics monitor.
5. Ball release will be determined as half way between the pitching events of maximum shoulder external rotation and maximum shoulder internal rotation (Oliver, Lohse, & Gascon, 2015).

Definitions

Kinematics – The temporal and spatial components of motion, i.e. position, velocity, and acceleration (Nordin & Frankel, 2001).

Kinetic Chain – The kinetic chain is a series of linked segments of the body that move together (Blazevich, 2017).

Kinetics: A branch of mechanics that examines the effects of forces and torques acting on the motion of an object (Beardsley, 2015).

Lumbopelvic-hip Complex (LPHC) – The lumbopelvic-hip complex (LPHC) encompasses the spine, torso, hips, pelvis, proximal lower limbs, and associated musculature of the abdomen and gluteals (Kibler et al., 2006).

Lumbopelvic Stability – The ability to prevent postural collapse of the vertebral column during dynamic tasks and return it to a stable position following movement (Willson, Ireland, & Davis, 2006).

Pitching Motion:

> *Lead Leg* – the leg contralateral to the throwing hand
>
> *Back Leg* – the leg ipsilateral to the throwing hand

Proximal-to-Distal Sequencing: States that the acceleration of the distal segment initially follows that of the proximal segment and then increases dramatically at peak velocity of the proximal segment. When the distal segment reaches peak acceleration, the proximal segment will be at a minimum (Putnam, 1993).

Summation of Speed Principle: The angular velocity of distal segments will be magnified in sequential order due to movement being initiated from larger and more proximal muscles (Bunn, 1972; Knudson, 2003).

CHAPTER 2

Review of Literature

The ability of the upper extremity to function efficiently, significantly depends on the strength and stability provided by the lower extremity and lumbopelvic-hip complex (LPHC), however the vast majority of overhead throwing literature focuses on the upper extremity (Fleisig et al., 1996a, 1996a; Garner, Weimar, & Madsen, 2009; W.B. Kibler et al., 2013; Klingenstein, Martin, Kivlan, & Kelly, 2012; Lewis, Foch, Luko, Loverro, & Khuu, 2015; Robb et al., 2010; Seroyer et al., 2010; D. F. Stodden, Langendorfer, Fleisig, & Andrews, 2006; Wilk, Meister, & Andrews, 2002; Wilk et al., 2000). It is the purpose of this study to investigate the correlation of LPHC stability via the single leg squat (SLS) to shoulder and elbow kinetics, and ball control (velocity and spin) during the fastball baseball pitch. To the author's knowledge, data available investigating the influence of LPHC stability in baseball pitching is limited. This chapter is a review of the literature regarding LPHC stability and baseball pitching. It is divided into the following subsections: 1] biomechanics of baseball pitching; 2] participation and injury in baseball; 3] injury implications in baseball pitching; 4] pitching performance measures; 5] the kinetic chain and LPHC; and 6] single leg squat (SLS).

Biomechanics of Baseball Pitching

Pitching is a 'whole body activity' that commences with drive from the large leg muscles to the hip and progresses through the trunk and shoulder. It continues with a 'whip-like' transfer of momentum through elbow extension and through the small muscles of the forearm and hand, transferring propulsive force to the ball (BSEMS, 2018). The main objective of the pitching motion is to produce velocity and accuracy by creating force and energy from the lower extremities. The repetitive nature of pitching, with the high velocities and large forces, places the upper extremity at high risk for injury. Proper pitching mechanics are needed in an attempt to minimize injury risk and maximize performance (Braun, Kokmeyer, & Millett, 2009; Fleisig, Andrews, Dillman, & Escamilla, 1995a; Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Weber, Kontaxis, O'Brien, & Bedi, 2014).

The baseball pitching motion is divided into six phases: windup, stride, arm cocking, arm acceleration, ball release, and arm deceleration (Figure 1) (Campbell, Stodden, & Nixon, 2010; Chu et al., 2016; Erickson et al., 2017; Fleisig et al., 1995a; Sauers et al., 2014; Yamanouchi, 1998). A synopsis of the events and the critical instances of high joint kinetics previously identified throughout the pitching cycle for arm cocking, arm acceleration, ball release and arm deceleration are described in the following paragraphs (Aguinaldo, Buttermore, & Chambers, 2007; Fleisig et al., 1995a; Keeley, Oliver, & Dougherty, 2011, 2012a; McFarland & Wasik, 1998).

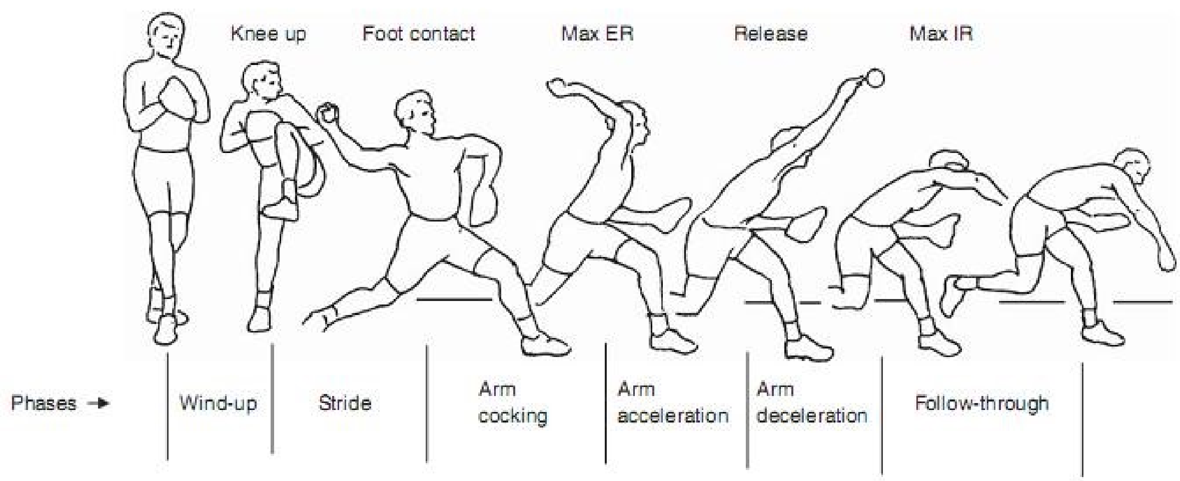


Figure 1. The six phases of the throwing motion. Phase 1 is the wind-up phase. Phase 2 is the planting of the striding foot. Phase 3 is the arm cocking phase, in which the arm reaches maximum external rotation. In Phase 4 arm acceleration, the ball is accelerated until Phase 5 starts with release of the ball and deceleration of the arm. Phase 6, the follow-through, rebalances the body until the motion stops (Braun et al., 2009).

The start of the baseball pitch begins with the wind-up. The goal of the wind-up is to position the body to deliver the pitch (Weber et al., 2014). During the wind-up, the pitcher transfers weight from bilateral leg support to unilateral support on the stance leg (throwing side leg). To achieve unilateral support on the stance leg, the major forces of the lower half have to rotate the body so that the non-throwing hip and shoulder are facing the target (Dillman, Fleisig, & Andrews, 1993; Weber et al., 2014). From this position, the pitcher positions the stance foot parallel and against the pitching rubber and lifts the stride knee to a position in front of the chest. The stride foot contacts the downhill slope of the mound, and the pitcher rotates their trunk and arm to pitch the ball.

Next begins the stride phase as the pitcher moves toward the target while separating and abducting their arms (Fleisig et al., 1998). During the stride phase, the pitcher begins to move toward the target by lowering the stride leg and separating the hand to abduct the arm (Weber et al., 2014). The goal of this phase is to allow increased energy production for transfer to the upper extremity (Dillman et al., 1993).

The arm cocking phase follows the stride phase which begins when the stride foot makes contact with the ground and ends with foot contact of the stride leg and maximal external rotation of the shoulder (BSEMS, 2018; Weber et al., 2014). The goal of the arm cocking phase is to create a stable base of support for which pelvic rotation, lumbar extension and upper extremity rotation can occur (Weber et al., 2014). Not usually described as separate events in the literature, arm cocking may be divided into two stages: early and late. Early arm cocking occurs during the end of the stride phase when the thrower begins their movement toward the target while late arm cocking phase occurs between stride foot contact and the point of maximal external rotation of the throwing shoulder (Seroyer et al., 2010; Weber et al., 2014). During arm cocking, the greatest angular velocities and largest change in shoulder rotation occur due to the rapid release of two forces: the stored elastic force of the tightly bound capsular tissue, and contraction from the internal rotator muscles. These forces can result in the greatest injury susceptibility to the upper extremity (Braun et al., 2009; Linter, Noonan, & Kibler, 2008). The lag behind of the elbow causes it to inwardly rotate placing a valgus force at the elbow resulting in shearing to the articular cartilage (BSEMS, 2018; Linter et al., 2008).

The arm acceleration phase is defined as the time between maximum shoulder external rotation and ball release, or the transition between maximum external rotation to internal rotation (Seroyer et al., 2010; Weber et al., 2014). The goal of this phase is to increase ball velocity (D. F. Stodden et al., 2006). Upper extremity musculature (subscapularis, pectoralis major, latissimus, and serratus anterior) reaches maximum activity during this phase to maintain a stable scapula base for which humeral internal rotation may occur (Seroyer et al., 2010; Weber et al., 2014).

Immediately following arm acceleration is ball release. Ball release is the point of reference in the pitching cycle to mark the transition from the arm cocking to arm deceleration phase. At ball release, the shoulder can be exposed to distractive forces of up to 950 N (213 lbs) (Kuhn, Lindholm, Huston, Soslowsky, & Blasier, 2003).

Arm deceleration begins with ball release and concludes when the shoulder reaches maximum internal rotation and elbow extension (Seroyer et al., 2010; Weber et al., 2014). The goal of this phase is to slow the arm down. During arm deceleration, distraction, shear and compressive forces act on the glenohumeral joint to counter humeral internal rotation and elbow extension (BSEMS, 2018; Lin, Wong, & Kazam, 2018). Hence, if compressive forces do not counteract the high distraction forces, injuries occur. Described as the most violent phase of the throwing cycle, the greatest amount of joint loading and eccentric contractile properties of the posterior shoulder musculature (teres minor, infraspinatus, and posterior deltoid) help misspend the enormous forces caused during the acceleration phase (Seroyer et al., 2010; Weber et al., 2014).

Last, a phase not discussed often in the literature is the follow-through. As the follow-through proceeds, the arm continues its forward movement and upper and lower extremity muscular activity begins to decrease until motion has concluded (Seroyer et al., 2010; Weber et al., 2014).

Pitching is a ‘whole body activity’ that commences with drive from the large leg muscles to the hip and progresses through the trunk and shoulder to the forearm. Understanding the biomechanics of the pitching motion can aid in identifying deviations in the throwing motion and subsequently injury patterns.

Participation and Injury in Baseball

Baseball is one of the fastest growing sports, with over 3 million participating in the United States alone and approximately 10 million around the world (BSEMS, 2018; “History of Baseball,” n.d.)**.** The history of baseball is of uncertain origins, however, traces of a game played with a bat and ball date back over 2000 years ago to ancient Egypt. Credited with the invention of baseball in 1839, was an army officer by the name of Abner Doubleday. By the late 18th century baseball became the first professional sport in the United States, and by the 20th century, the game reached international status (“History of Baseball,” n.d.). The increase in baseball participation is credited to many players beginning formal play in their adolescent and high school years. After which, approximately 25,000 progress to compete at the collegiate level and a small percentage of go on to play in the minor or major league (“How many kids are playing baseball in the world?,” 2015; “Probability,” 2018; Melugin et al., 2018). As a result, increased participation has lead to a rise in injury susceptibility; therefore the role and need of health care providers to care for the injured baseball players has grown and the need for researchers and clinicians to act to prevent injuries has become paramount (Andrews & Fleisig, 1998; Fleisig & Andrews, 2012a; Kerut et al., 2008; Lyman & Fleisig, 2005). Over recent decades the increase in injury susceptibility may have been attributed to amplified intensity of training, year-round play, and unmonitored work load during training (Caine, 2010). As the awareness of injury susceptibility has grown, continual research has focused on injury epidemiology and prevention (Braun et al., 2009; Conte, Requa, & Garrick, 2001; Fleisig & Andrews, 2012a; Fleisig et al., 1996a; Melugin et al., 2018, 2018; Oliver, 2014; Sabick, Torry, Lawton, & Hawkins, 2004).

Investigation into youth baseball injury prevention and safety strategies has also grown and continues to be examined (Davis et al., 2009; Fleisig & Andrews, 2012a; Huang, Wu, Learman, & Tsai, 2010; Lyman et al., 2002; Melugin et al., 2018; Oliver & Weimar, 2015; Oliver, Weimar, & Henning, 2016; Sabick, Kim, Torry, Keirns, & Hawkins, 2005; Sabick et al., 2004). During the early years of youth, undeveloped growth plates remain open which can lead to stress related injuries as a result of the repetitive traumas of baseball pitching. It is these stresses that expose younger athletes to the vulnerability of overuse injuries, because they are now exposed to the same throwing forces as mature athletes (BSEMS, 2018; Melugin et al., 2018). Various studies on youth pitchers and prevention strategies have been conducted via surveys or biomechanical analyses, to determine risk factors to the prevention of injuries (Dun, Kingsley, Fleisig, Loftice, & Andrews, 2008; Fleisig & Andrews, 2012a; Fleisig et al., 2011;

Oliver et al., 2016; Olsen, Fleisig, Dun, Loftice, & Andrews, 2006). In a 10-year study by Fleisig et al, the authors quantified the growing incidence of throwing injuries in young baseball pitchers. The authors hypothesized that the increased amount of pitching, throwing curveballs at a young age, in addition to also playing catcher has increased a young pitcher's risk of injury. The interviews concluded that the risk factors of injury increased in players age 9-13 year olds who pitched more than 100 innings in a year as well as those who concurrently played the position of catcher. These risk factors lead to the authors recommending limiting the number of innings pitched per year and encouraging youth to play positions other than catcher (Fleisig et al., 2011).

Repeatedly executing proper pitching mechanics is a fundamental skill that all pitchers must learn. Factors associated with improper mechanics are poorly understood and have been infrequently studied in youth pitchers (Pasternack, Veenema, & Callahan, 1996). Like the fastball, breaking pitches place high loads on the upper arm (Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998). Three studies have demonstrated that breaking pitches are known to be stressful throws that increase the risk of arm pain and injury potential (Fleisig & Andrews, 2012b; Lyman et al., 2002; Matsuo, Fleisig, Zheng, & Andrews, 2006). Lyman et al., conducted studies with youth baseball pitchers (9-14 years old) and found multiple risk factors for shoulder and elbow pain. Post-game questionnaires revealed a significant association between the number of pitches thrown in a game and during the season to elbow pain and shoulder pain. The authors concluded that youth pitchers should be cautioned about throwing breaking pitches (curveballs and sliders) and engaging in high pitch counts because of the greater risk of elbow and shoulder pain (Lyman et al., 2002). Similar findings to Lyman et al, Fleisig and Andrews, 2012 contributed to the literature by noting the months pitched per year was also a contributor to increased shoulder and elbow pain in youth (Fleisig & Andrews, 2012a). Matsuo et al., investigated the effects of shoulder abduction angle and lateral trunk tilt on elbow varus torque, by means of computer simulations and regression analyses on fast and curveballs. As it has been reported that breaking pitchers have a higher incidence of more severe elbow injury than overhand pitches. The investigators noted that decreased trunk tilt and increased front knee flexion were characteristic of lower velocity fastballs. These results indicate that elbow and shoulder kinetics between the fastball and curveball imply that throwing curveballs is no more dangerous for a collegiate pitcher than is throwing a fastball (Matsuo et al., 2006).

Shoulder and elbow pain are well-recognized occurrences in youth baseball pitchers and has been directly associated with throwing when fatigued. It is generally accepted that playing with fatigue is a primary predictor of injury in youth baseball (Fleisig et al., 2011; Lyman et al., 2002; Olsen et al., 2006). As a pitcher approaches muscular fatigue, pitching mechanics and biomechanical variables will be altered, leading to a decrease in performance and amplified susceptibility to injury (Chalmers et al., 2017; Fleisig et al., 2011; Lyman et al., 2002; Oliver et al., 2016; Olsen et al., 2006). In regards to pitch count regulations, two studies have offered insight into pitch count regulation and injury (Andrews & Fleisig, 1998; Oliver et al., 2016; Olsen et al., 2006). In a pilot study examining 172 youth pitchers (9-12 years old) for one season, it was found that the risk of injury in a game increased 20% for every inning pitched and 10% for every 10 pitches thrown (Andrews & Fleisig, 1998). Additionally, in an examination of pitchers with and without a history of arm injury, it was found that those pitchers with injury had pitched significantly more months per year, games per year, innings per game, pitches per game and year, and warm-up pitches before a game (Olsen et al., 2006). Those same pitchers were more frequently starting pitchers, pitched in more showcases, pitched with higher velocity, and pitched more often with arm pain and fatigue. The authors concluded that decreases in pitching showcases and pitched velocity, may reduce the incidence of injury to adolescent pitchers (Olsen et al., 2006). Based on previous findings, regarding pitch types, pitch volume, pitch mechanics as well as the number of pitches and innings permitted have been established to prevent injury to the youth athlete (Andrews & Fleisig, 1998; Braun et al., 2009; BSEMS, 2018; Fleisig & Andrews, 2012a; Fleisig et al., 1995a, 1996a).

As with youth, high school baseball athletes are also at risk for overuse injuries, but their susceptibility to baseball related pitching injury tends to be more severe in their throwing arm (Fleisig et al., 2006). In a report of shoulder injury rates among high school baseball and softball athletes, Krajnik et al, 2010 determined that approximately 10% of shoulder injuries to pitchers required surgery (Krajnik, Fogarty, Yard, & Comstock, 2010). Although the most common baseball pitching injuries tend to involve the rotator cuff, the dramatic rise in ulnar collateral ligament (UCL) injuries has received much attention throughout the baseball community among high school players (Dun et al., 2008; Hang, Lippert, Spolek, Frankel, & Harrington, 1979; Hurwit et al., 2017; Lyman et al., 2002). Injuries of the UCL can range from minor damage and inflammation to a complete tear of the ligament. Athletes who complained of pain on the medial side of the elbow frequently noticed decreased throwing velocity (American Academy of Orthopedic Surgeons, 1995). Some orthopedic practices have seen a six fold increase in the number of elbow surgeries performed on high school pitchers from 2000-2004 compared to 1994–1999 with approximately 13% of those surgeries being UCL reconstructions (Fleisig et al., 2006; Petty, Andrews, Fleisig, & Cain, 2004). Petty et al, 2004, in a retrospective study, investigated the success rate of UCL reconstruction following injury in high school baseball pitchers. The authors were also interested in the contributors to UCL injury. Follow-up physical examinations and questionnaires were collected 35 months post UCL surgery from 27 former high school baseball players. From the follow-up and questionnaires, the authors identified six potential risk factors: year-round throwing, seasonal overuse, event overuse, throwing velocity more than 80 mph, throwing breaking pitches before age 14, and inadequate warm-ups. Findings concluded that high school players who identified with 3 or less potential risk factors including one factor being an overuse factor, returned to baseball at the same or higher level after UCL surgery. Successful UCL surgery of players that were pitchers found they had an average self-reported fastball velocity of 83 mph and more than half threw breaking pitches before age 14. Thus, the authors concluded that UCL reconstruction for high school players can be performed with success, in light of the identified risk factors (Fleisig et al., 2006; Petty et al., 2004).

With baseball pitching being one of the fastest human motions (Dillman et al., 1993), it has been demonstrated to have greater injury implications due to the tremendous force and torque experienced by the shoulder and elbow during pitching (Fleisig et al., 1995a; Sabick et al., 2004; Werner, Gill, Murray, Cook, & Hawkins, 2001). Pitching injuries have increasingly become a serious concern of parents, coaches, and medical professionals. Whether an injury results from overuse during a game, season, or career, identifying the contributing factors has been difficult. Injury prevention in youth baseball is mainly aimed at avoiding overuse, this holds true up to high school and professional levels. The adoption of guideline recommendations from USA Baseball Medical & Safety Advisory Committee, upper extremity stretching, lower extremity strengthening and range of motion exercises are useful practices in preventing injury. Although there is an increasing scientific interest into baseball injury epidemiology and prevention, more research needs to be conducted on this important topic, to avoid future injury.

Injury Implications in Baseball Pitching

As one of the largest organ in the human body, skeletal muscles consume the most energy of any organ allowing for efficient movements of varying intensities during different movement patterns. Tension is one of those important skeletal muscle biomechanical properties (Đorđević, Stančin, Meglič, Milutinović, & Tomažič, 2011). The estimation of skeletal muscle tension requires an understanding of human motion, such as in this case the baseball pitch. Hence, the mechanisms that contribute to the decline in muscle tensions is vital to understanding the forces that can lead to injury in the overhead athlete. During the pitching motion, forces approach crucial tensile strengths of the soft tissues that support the upper extremity. In an experiment of cadaveric tensile strengths, Reeves, (1968) quantified the amount of stretch a tendon could withstand before dislocation of the shoulder occurs. The authors performed a tensiometry study of the subscapularis tendon and the anterior capsule of the shoulder. Under increasing loads, the author found that the anterior aspect of the capsule resists approximately 800 to 1200 N in twenty to thirty-year-old individuals (Reeves, 1968). It was concluded that tensile strength varied with age. Compared to the elderly, the anterior shoulder joint capsule was weakest in the younger patients, while the elderly showed more weakness in the tendons, likely due to calcification of the tissue. This suggests that injury may not be due to a mechanism but rather weakness in the structures (Reeves, 1968).

To achieve a better understanding of the forces acting on the shoulder resulting in injury, available literature on shoulder kinetics has often been discussed (Aguinaldo et al., 2007; Fleisig et al., 1995a; Keeley, Oliver, & Dougherty, 2012b; McFarland & Wasik, 1998). The two kinetic parameters most often discussed are, anterior force, which peaks near the time of maximum shoulder external rotation, and proximal or compressive force, which peaks near ball release. Shortly before maximum external rotation, shoulder internal rotation torque and elbow varus torque have been reported as high as 67 N-m and 64 N-m, respectively. After ball release, shoulder compressive force has been reported as high as 1090 N. The above study concluded that the inability to generate sufficient elbow and shoulder torques may result in injury (Fleisig et al., 1995a). Keely et al, (2012) conducted a study investigating the incidence of shoulder pain in youth pitchers and the incidence of shoulder pain to shoulder kinetics at two the critical time points of arm cocking and arm acceleration. The authors revealed that while shoulder anterior force during arm cocking was not a significant predictor of reported shoulder pain, proximal force during arm acceleration was a pain predictor. This is an important finding as both anterior force and proximal/compressive force have been postulated as possible injury mechanisms. The results of this study support the notion that a proximal or compressive force during pitching may contribute to the incidence of shoulder pain, but also contradict this notion with regard to anterior force (Fleisig et al., 1995a; Keeley et al., 2012b).

Both Fleisig and Aguinaldo have investigated kinetic differences among various levels of competition of baseball pitching. Fleisig et al, 1999 examined differences between elbow varus, elbow flexion, shoulder internal rotation and anterior force. Aguinaldo et al, 2007 investigated trunk rotation and shoulder rotational torques during the pitching cycle. Fleisig noted significant differences during arm cocking, acceleration, and deceleration phases. Although pitching mechanics did not change significantly with level, the observed significant kinetic differences suggest greater injury risk at higher competition levels. Concluding that adult pitchers are more susceptible to injury as a result of increased strength and muscle mass during the arm cocking and acceleration phases (Fleisig et al., 1999). Aguinaldo noted that professional pitchers were able to rotate their trunks later in the pitching cycle attributing to lower amounts of shoulder torque when compared to other groups. These findings suggest that specific throwing patterns can be applied to increase the efficiency of the pitch, which would allow a player to improve performance with decreased risk of overuse injury (Aguinaldo et al., 2007).

Investigations of the upper extremity during throwing has added to our current knowledge during each phase of the pitching cycle, and it has helped to guide the development of injury prevention and rehabilitation programs. Improving the overall understanding of throwing mechanics and performance can eventually lead to new ways to prevent injuries in baseball throwers and better address their rehabilitation strategies.

Pitching Performance Measures

A successful pitcher alters pitch velocity and movement characteristics to keep hitters disillusioned and deter their anticipation of a particular pitch type (Seroyer et al., 2010)**.** In baseball pitching, ball velocity is the over arching goal for every pitch. Ideally, pitchers strive to obtain the highest ball velocity while still maintaining control of the ball. The fastball pitch is named for the fact that it is designed to produce the greatest ball velocity of all pitch types. For the purposes of this literature review, we will focus on the commonly utilized four-seam fastball (Figure 2)**.**

Figure 2. The four-seam grip.

Ball velocity depends on a variety of biomechanical factors and previous research has directly related it to the amount of external rotation that the shoulder achieves (Dillman et al., 1993;

Stodden et al., 2005). In order to generate maximum ball velocity in the most efficient manner, the lower and upper extremities must work in a synchronous and coordinated fashion. Elite pitchers have been known to generate ball velocities that exceed 90 mph (40.23m/s); during which the shoulder externally rotates at angular velocities of up to 7000 degrees/sec (Dillman et al., 1993). While elite throwers are able to achieve high angular velocities, the forces that are generated place the soft-tissue structures that surround the shoulder near fatigue strength which may subsequently lead to injury (Dillman et al., 1993; Fleisig et al., 1999; Sabick et al., 2005; Werner et al., 2001).

Precision, the ability to throw the ball to a predetermined location, is related to the pitcher's ability and reproducibility to create specific arm positions and exact timing of ball release (Hore et al, 1996). Baseball pitchers striving to achieve the greatest ball velocity must also have a command of the ball. A ball pitched in the strike zone, at the desired location and with the desired spin would define a pitcher as having ball command. Thus, it is a pitcher's goal to deliver a ball with the greatest velocity and precision. However, if the pitcher can add the element of ball movement or spin to the high velocity and precision then that is the ultimate performance goal. Spin, in combination with ball velocity, determines the direction and amount of "break" imparted to a pitched ball. The manipulation of ball spin rates are critical elements that allow pitchers to achieve a superior level of performance, by altering the direction and magnitude of the drag and lift forces (Nagami, Higuchi, & Kanosue, 2013). Several studies have presented scientific analyses of the effect of aerodynamic factors on ball spin of the pitched baseball (Mehta & Pallis, n.d.; Nagami et al., 2013; Nathan, 2008). Fastballs are usually thrown with backspin creating a higher spin rate, thus generating a larger magnus force, leading to the impression of it rising and the hitter's perception of the "rising fastball." Conversely, a low spin rate fastball have a smaller magnus force, and is thus a “sinking fastball” (“Spin Rate,” 2016). Slower pitches typically have more ball movement, making the ball more difficult to hit. To the author’s knowledge, there have been no formal investigations into the effect of ball spin on the kinetics to the upper extremities. The aforementioned performance measures are key components to understanding how pitches move, and how they can be improved (“Spin Rate Part II,” 2016). The manipulation of ball spin rates are critical elements that allow pitchers to achieve a superior level of performance.

The Kinetic Chain and LPHC

The dynamic movement of baseball pitching requires the contributions of the lower extremity, lumbopelvic-hip complex (LPHC), and upper extremity. This total body interactive system is better known as the kinetic chain. The kinetic chain is a series of interdependent links working synergistically for optimal movement (Kibler 1995; Putnam 1993). Interdependent segments working synergistically allows for sequential energy transfer to the next distal segment as it progresses from proximal (lower extremity) to the distal (upper extremity) (Chu 2016; Kibler 1995; Kibler 2006; Kibler 2013; Putnam 1993; Sciascia 2012). The kinetic chain is made up of length and force dependent muscle groups that allow stability around one joint (length) or multiple muscles to move several joints to develop force (Kibler et al., 2006). The proximal segments of the lower extremity act as a conduit for energy transfer to the upper extremity, with the scapula being the link in the kinetic chain that transfers the forces and energy from the lower extremity and LPHC to the upper extremity. It is known that the legs and trunk serve as the major force generators, with approximately 50% of the energy generated from the lower extremity (Campbell et al., 2010; Chu et al., 2016; Kibler et al., 2006, 2013; Seroyer et al., 2010). It is vital that the proximal segments function efficiently to provide proximal stability for distal mobility of the upper extremity, so once the lower extremity creates the motion, it must then change roles and work to stabilize. This requires adequate strength, stability, and mobility of the lower extremity, LPHC, and upper extremity.

The LPHC, also referred to as the core, allows for the postural changes and adaptations during movements. LPHC stability is the center of all movement and the center of an athletes' performance. During the pitching motion the body acts as a kinetic chain where forces are transmitted from one joint to another in succession. LPHC strength is necessary to reduce perturbations and provide a stable base for distal mobility.

The kinetic chain has been examined in regards to overhead throwing and its impact on injury and performance (Kibler 2013; Weber 2014; Kibler 2013; Sciascia, 2012; Lintner 2008; Seroyer 2009). An ineffective kinetic chain often leads to upper extremity injury, mainly of the shoulder and elbow, as result of repetitive overuse and poor throwing mechanics (Chu et al., 2016; Kibler et al., 2006, 2013; Litner, 2008; Sauers et al., 2014; Seroyer et al., 2010). Given the frequency of shoulder and elbow injuries in overhead athletes, developing an efficient kinetic chain is vital for energy production, accuracy and increased throwing velocity (Chu et al., 2016; Kibler et al., 2006, 2013; Sauers et al., 2014; Seroyer et al., 2010). The kinetic chain can be explained through its five major objectives: (1) provide a stable base for distal segment mobility; (2) produce interactive moments at distal joints greater than the energy and force the joint itself could produce; (3) utilize muscle activation patterns to link multiple body segments temporarily into one; (4) maximize large force development in the LPHC and energy transfer distally to the hand; and (5) produce torques that decrease deceleration forces linked to injury (Chu et al., 2016; Kibler et al., 2006).

A major component of the kinetic chain in dynamic overhead movements is the LPHC (Klingenstein et al., 2012; Laudner, Moore, Sipes, & Meister, 2010; Laudner, Wong, Latal, & Meister, 2018; Oliver, 2014; Robb et al., 2010; Sauers et al., 2014; Scher et al., 2010). The lower extremity consists of the centrally located musculoskeletal core, also known as the LPHC and includes all musculature that either originates or inserts on the lumbar spine, pelvis and femur (Mullaney et al., 2005). The LPHC encompasses the large muscles of the hips and pelvis that stabilize the lower extremity and are able to generate substantial amounts of force and power to the upper extremity. Specifically the musculature of the lower extremity and LPHC are thought to play an integral role in both accelerating and decelerating the upper body (Campbell et al., 2010; Elliott, Grove, & Gibson, 1988; Mullaney et al., 2005). The concept of sequential force development in a proximal to distal sequence is the framework of comprehending dynamic overhead movement. Examination of segmental movements in a proximal to distal fashion, the kinetic chain can be divided into three major components of the lower extremity, LPHC, and upper extremity. Thus, the link from the lower extremity to the upper extremity is the LPHC. Stability of the LPHC is achieved by the intrinsic core musculature creating a rigid cylinder via increased abdominal pressure to create interactive moments which occur preceding upper limb movement (Kibler, 2006).

In addition to LPHC stability, the influence of the LPHC on scapular stability and mobility is also of concern in overhead athletes (Kibler 1991; 1995; 1998; McMullen 2000; Burkhart 2003; DeMay 2013; Oliver 2015). A stable LPHC and scapula are warranted in repetitive throwing to reduce upper extremity injury. The scapula functions to provide a stable platform for the humeral head during rotation and elevation, while transferring kinetic energy from the lower limbs and trunk to the upper extremity. The work of Kibler has added greatly to our understanding of scapular dynamics and injury prevention and treatment (Kibler, 1998). It has been estimated that only half of the kinetic energy imparted to the ball results from arm and shoulder action. The remaining half is generated by lower-limb and trunk rotation and is transferred to the upper limb through the scapulothoracic joint in overhead throwers (Chu et al., 2016; Kibler et al., 2013; Sciascia et al., 2012).

The dynamic motion of the baseball pitch requires the efficient generation and transfer of energy from the lower extremity and LPHC to the upper extremity and on to the most distal segment of the hand and onto the ball. Within this dynamic energy transfer system, each segment also displays the summation of speed principle where the adjacent proximal segment reaches top speed, and then the next distal segment reaches top speed, accumulating speed throughout the chain in a proximal to distal manner (Putnam, 1993; Seroyer et al., 2010). Thus, the majority of energy generation should occur from the lower extremity and it is the integrity of the LPHC that ultimately dictates that energy transfer. Dysfunctional movement patterns within the human body during athletic actions are a result of impairments within this system of the kinetic chain.

The mechanics of the baseball pitch creates large forces that are not restricted to the shoulder alone but rather are imparted across all the anatomical joints involved in the throwing motion. Forces at the shoulder may be greater in an athlete who is compensating for injuries or range-of-motion (ROM) restrictions at joints some distance from the shoulder (eg, trunk, hip, knee, ankle) (Elliott et al., 1988). With increased focus on the lower extremity in baseball pitching, examination of hip biomechanics has become prevalent. Several investigators have suggested that evaluation of hip muscle performance may be important in predicting injury in baseball pitching (Krause, Schlagel, Stember, Zoetewey, & Hollman, 2007). Additionally, research has been focused on the characteristics of hip ROM in baseball pitchers and position players, though minimal data regarding the relationship between hip ROM and injury has been reported (Ellenbecker, 2014; Kevin G. Laudner et al., 2010; Robb et al., 2010; Sauers et al., 2014; Scher et al., 2010). However, data regarding hip ROM and upper extremity kinematics are prevalent. In an examination of youth participants, a relationship associating hip ROM and scapular kinematics was reported (Oliver & Weimar, 2015). Additionally, a relationship between pelvic stabilizing musculature and scapular stabilizing musculature has also been established (Oliver, Weimar, & Plummer, 2015). Thus, reiterating the integral link of the lower extremity, LPHC and upper extremity but also the importance of proximal stability for distal mobility.

The dynamic motion of the baseball pitch requires the kinetic chain to work efficiently from the most proximal lower extremity through the LPHC trunk and upper extremity. More importantly, for the most efficient energy transfer from the lower extremity to the upper extremity, there has to be proximal stability of the LPHC for the ultimate distal mobility of the wrist and hand for ball release.

Single Leg Squat

The ability of the upper extremity to function efficiently depends upon the LPHC to provide proximal stability for distal mobility, as well as to generate the forces and energy necessary to perform overhead throwing tasks. Previous research has also suggested the use of clinical tests of LPHC function to identify any proximal dysfunction that may decrease upper extremity function (Chaudhari, McKenzie, Borchers, & Best, 2011; Gilmer, Gascon, & Oliver, 2018; Gilmer, Washington, Dugas, Andrews, & Oliver, 2017; Laudner et al., 2018, 2018; Solomito, Garibay, & Nissen, 2018). With the known importance of the LPHC in dynamic overhead movements, the ability to classify LPHC stability becomes vital. The single leg squat (SLS) is a common clinical assessment tool used to examine LPHC control and stability

(Chaudhari et al., 2011; Claiborne et al., 2006; Crossley et al., 2011; DiMattia et al., 2005; Zeller, McCrory, Kibler, & Uhl, 2003). Additionally, the SLS has been proven as a valid and reliable test of LPHC function (Claiborne et al., 2006; Crossley et al., 2011; Ireland, Willson, Ballantyne, & Davis, 2003; Willson et al., 2006). The goal of the SLS is to reveal dysfunction at multiple segments of the kinetic chain in multiple planes of motion (Henning, 2016). The SLS accentuates lower extremity weaknesses in the LPHC (Claiborne et al., 2006; Crossley et al., 2011; DiMattia et al., 2005; Nishiwaki et al., 2006; Zeller et al., 2003). Particular attention focuses on the following three abnormal movement patterns: contralateral hip drop (trendelenburg), knee valgus angulation during descent, and excessive forward lean (Ellenbecker, 2014).

Disruptions in the kinetic chain, specifically LPHC stability, have been associated with decreased pitching performance and increased risk of injury (Chaudhari et al., 2011; G. G. Gilmer et al., 2018, 2017; K. Laudner et al., 2018). In an examination of professional baseball pitchers and LPHC stability, it was found that those who were classified as unstable, produced more walks and hits per inning than the pitchers who were considered stable (Chaudhari et al., 2011). Similarly, in an examination of professional baseball pitchers' LPHC stability and injury, it has been found that those lacking LPHC stability have an increased likelihood of spending more days on the disabled list than those with a stable LPHC (Chaudhari, McKenzie, Pan, & Oñate, 2014).

Specifically examining the SLS in throwing athletes, Gilmer et al investigated the effects of LPHC instabilities on segmental sequencing and maximum velocities during the overhead throw of adolescent softball players. LPHC instability was classified as knee valgus of greater than 15 degrees at 45 degrees of knee flexion during the decent phase of the SLS. The authors found no significant differences between stability groups in segmental sequencing and maximum velocities. They suggested the results are not a function of LPHC instability amongst this specific group of athletes, and that the SLS may not accurately quantify LPHC stability in regard to throwing (G. G. Gilmer et al., 2018). Similarly suggestive of the effects of LPHC instability is a mechanism in which energy can be lost, thus affecting throwing mechanics (G. G. Gilmer et al., 2017). The authors concluded that with proper lumbopelvic-hip control a pitcher may be able to generate additional energy and efficiently transfer it to the throwing hand.

As new evidence continues to highlight the role of LPHC control among overhead athletes, understanding LPHC stability profiles via SLS performance can prove beneficial. It is known that the lower extremity and trunk play a major role in kinetic chain efficiency during baseball pitching (Chaudhari et al., 2011; Kibler et al., 2006; Oliver & Keeley, 2010a). Additionally, LPHC stability and control has been associated with increased pitching performance, decreased upper extremity kinetics, and ultimately decreased injury susceptibility (Chaudhari et al., 2011, 2014; Keeley, Oliver, Dougherty, & Torry, 2015). Thus, implementation of the SLS to classify LPHC stability as well as the implementation of LPHC training and conditioning within overhead throwing athletes daily repertoire is recommended (Chaudhari et al., 2011; Kibler et al., 2006; Laudner et al., 2018; Oliver & Keeley, 2010a, 2010b; Stodden et al., 2001).

CHAPTER 3

Methods

Movement patterns of the lower extremity as well as the influence of those movements on upper extremity loads, injury prevention and performance enhancement are crucial to the understanding of baseball pitching. The purpose of this study was to investigate the correlation of lumbopelvic-hip complex (LPHC) stability, via the single leg squat (SLS), to shoulder and elbow kinetics, and ball control (speed and spin) during the fastball baseball pitch. The role of this chapter is to outline and describe the methodology that was used for this study. This chapter is divided into: experimental approach to the problem, participants, setting, instrumentation, design and procedures, and data analysis.

Experimental Approach to the Problem

The aim of this study was to examine the correlation of LPHC stability, via the SLS, to shoulder and elbow kinetics, and ball control (speed and spin) during the fastball baseball pitch. LPHC stability was determined using a SLS assessment, as it is known to be a consistent test for lower extremity and LPHC instability (Bolgla & Malone, 2004; Claiborne et al., 2006; Crossley et al., 2011; DiMattia et al., 2005; G. G. Gilmer et al., 2017; Zeller et al., 2003). Previous studies have shown that knee valgus during the SLS provides insight into LPHC stability (G. G. Gilmer et al., 2017; Plummer & Oliver, 2015). The criterion for SLS performance was based on the kinematics of frontal plane total knee excursion (maximum valgus) to determine the participants LPHC stability. The independent variable in this study was SLS performance, specifically the degree of knee valgus (Bolgla & Malone, 2004; Claiborne et al., 2006; Crossley et al., 2011;

DiMattia et al., 2005; G. G. Gilmer et al., 2017; Zeller et al., 2003). The dependent variables were the maximum kinetic values of the shoulder and elbow (force) during two pitching events (shoulder maximum external rotation and ball release) and three pitching phases (arm cocking, arm acceleration and arm deceleration) and ball speed and ball spin (Seroyer et al., 2010).

Participants

Baseball pitchers ranging from 9 to 25 years old were recruited to participate. Selection criteria included participants actively participating on a competitive baseball team, in good physical condition, and free from injury within the last 6 months. Additionally, any potential participant who had an allergy to adhesive tape was excluded. A health history questionnaire was used to determine participation eligibility (Appendix A). Prior to participation, the primary investigator reviewed the questionnaire to exclude any participants that might be at risk of injury. Based on this recruitment, the results from this study were able to be delimited across a larger population of baseball pitchers. Prior to any participation, parental assent and participant consent was obtained. All participants and parents read and signed an informed consent document approved by the Auburn University Institutional Review Board (Appendix B). The least number of participants that were chosen to participate was based on an *a-priori* power analysis. An a priori power analysis indicated that a minimum 19 baseball pitchers were needed to achieve an 80% power when employing the traditional 0.05 criterion of statistical significance with a large effect size (r = .50).

Setting

All data collections were conducted in a controlled laboratory setting in the Sports Medicine and Movement Laboratory within the School of Kinesiology at Auburn University.

This location has the space and necessary equipment to successfully execute and fulfill the objectives of this study.

Instrumentation

Ball Speed and Ball spin

Ball speed (mph) and ball spin (rpm) were measured using the Rapsodo® (Rapsodo Ball Flight Analytics Monitor, St. Louis, MO, USA) (Figure 3). Per the manufacturer's instructions, positioning of the Rapsodo® should be placed six feet behind the catcher.

Figure 3: The Rapsodo®.

Kinematics and Kinetics

Kinematic and kinetic data were collected at 240 hertz (Hz) using an electromagnetic tracking system (trakSTAR™, Ascension Technologies, Inc., Burlington, VT, USA) synchronized with The MotionMonitor (Innovative Sports Training, Chicago, IL., USA). Fourteen electromagnetic sensors were affixed to the skin at the following locations (Figure 3): (1) posterior aspect of the trunk at the first thoracic vertebrae (T1) spinous process; (2) posterior aspect of the pelvis at the first sacral vertebrae (S1); (3-4) bilateral distal/posterior aspect of the upper arm at the deltoid tuberosity, centered between the radial and ulnar styloid processes; (5-6) bilateral flat, broad portion of the acromion of the scapula; (7-8) bilateral distal/posterior aspect of forearm; (9-10) bilateral distal/lateral aspect of the upper leg; (11-12) bilateral distal/lateral aspect of the lower leg; and (13-14) bilateral dorsal aspect of the third metatarsal of the foot (Oliver & Plummer, 2011; Plummer & Oliver, 2015). A fifteenth, moveable sensor was attached to a plastic stylus for the digitization of bony landmarks (Wu et al., 2002, 2005). In order to ensure accurate identification and palpation of bony landmarks, the participant stood in anatomical neutral throughout the digitizing process. Using the digitized joint centers for the ankles, knees, hips, T12-L1, and C7-T1, a link segment model was developed.

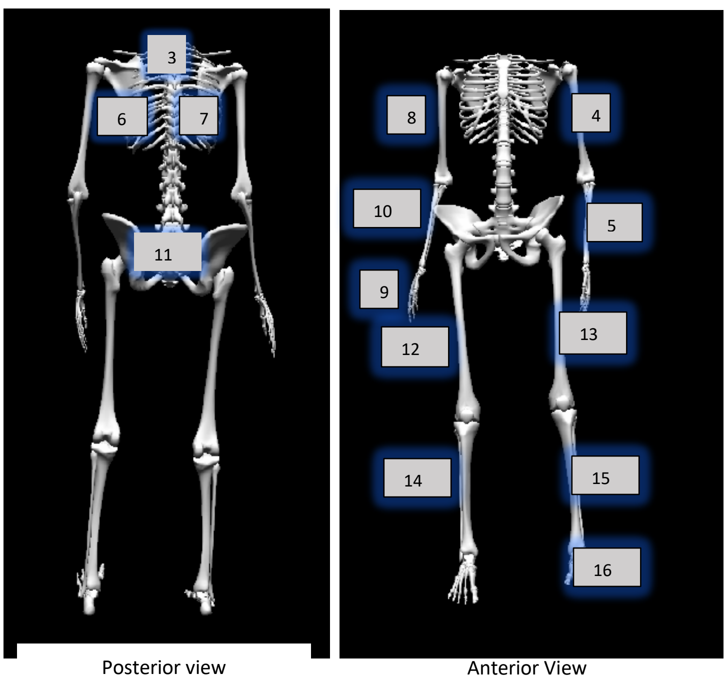


Figure 4. Electromagnetic sensor placement.

Joint centers were determined by digitizing (Table 1) the medial and lateral aspect of a joint and calculating the midpoint between those two points (Wu et al., 2002). The knee and ankle joints were defined as the midpoint between the lateral femoral condyles and medial and lateral malleoli respectively, and the spinal column was defined as the space between C7-T1 and T12-L1. The shoulder joint center relative to the scapula was calculated using the rotation method, and the hip joint centers relative to the sacrum was determined by digitizing. The rotation method involves the investigator stabilizing the joint then passively moving the limb into six different positions in a small, circular pattern. The rotation method has been validated to provide accurate positional data (Huang et al., 2010).

Table 1. Description of bony landmarks to be digitized.

Bony Landmarks	Digitized Bony Processes
Trunk	
Seventh Cervical Vertebra (C7)	C7 Spinous Process
Twelfth Thoracic Vertebra (T12)	T12 Spinous Process
Eighth Thoracic Vertebra (T8)	T8 Spinous Process
Suprasternal Notch	Most Cranial Aspect of Sternum
Xiphoid Process	Most Distal Aspect of Sternum
Humerus	
Medial Epicondyle	Medial Aspect of Humeral Epicondyle
Lateral Epicondyle	Lateral Aspect of Humeral Epicondyle
Forearm	
Radial Styloid Process	Lateral Aspect of Radial Styloid
Ulnar Styloid Process	Medial Aspect of Ulnar Styloid
Hand	
Third Metacarpalphalangeal Joint	Dorsal, Distal Aspect of the 3rd Metacarpal
Third Distal Phalanx	Most Distal Aspect of the 3rd Phalanx
Knee	
Lateral Femoral Condyle	Lateral Aspect of Femoral Condyle
Medial Femoral Condyle	Medial Aspect of Femoral Condyle
Ankle	
Lateral Malleolus	Lateral Aspect of the Distal, Fibular Head
Medial Malleolus	Medial Aspect of the Distal Tibia

Intrarater reliability of digitization was determined during data collections of 6 athletes. The investigator reported intraclass correlation coefficients (3,1) of 0.958 for all measurements. To ensure accurate identification and palpitation of bony landmarks, the participant stood in a neutral stance throughout the duration of the digitization process so that their body segments could be defined. Raw data of sensor position and orientation were based on a local coordinate system for each of the described body segments (Table 2). Kinematic data were used to identify the pitching events and phases within the pitching cycle. Joint kinetics were determined through inverse dynamics calculated by The MotionMonitor employing previously described techniques modeling the arm and torso as a 3 link rigid segment (Feltner & Dapena, 1986; Fleisig et al., 1999; Keeley, Hackett, Keirns, Sabick, & Torry, 2008; Sabick et al., 2004). Body segment mass and inertial properties were obtained from previous literature and scaled to the participants' height and mass (Clauser, McConville, & Young, 1969; Hinrichs, 1990). All arm kinetic data were calculated in reference to the proximal segment axis through a top down method by MotionMonitor software. Inverse dynamic equations for all joint kinetics can be found in Appendix D. Shoulder and elbow forces were defined as the resultant force acting along the X, Y, and Z axis. The force along the X axis was defined as the anterior/posterior force; the compression distraction force was along the Y axis; and the linear force in along the Z axis was defined as an abduction/adduction force at the shoulder and a varus/valgus force at the elbow. The world axis configuration was the positive Y-axis in the vertical direction. The positive X-axis was defined in the direction of movement, and the positive Z-axis was to the right and orthogonal to the Y and X-axis. Position and orientation data were calculated using Euler angle sequences consistent with the International Society of Biomechanics standards and joint agreements (Wu et al., 2002). Root mean square of all raw data were filtered using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz (Plummer & Oliver, 2015). All data were time stamped through the MotionMonitor and synchronized passively with a data acquisition board.

Table 2: Angle orientation decomposition sequences.

Segment	Axis of Rotation	Angle
Trunk		
Rotation 1	Z	Flexion /Extension
Rotation 2	X’	Left Lateral Flexion /Right Lateral Flexion
Rotation 3	Y”	Right Rotation /Left Rotation
Shoulder		
Rotation 1	Y	Plane of Elevation
Rotation 2	X’	Elevation
Rotation 3	Y”	Internal Rotation / External Rotation
Elbow		
Rotation 1	Z	Flexion /Hyperextension
Rotation 2	X’	Varus/Valgus
Rotation 3	Y”	Pronation /Supination
Knee		
Rotation 1	Z	Flexion/Extension
Rotation 2	X’	Varus/Valgus
Rotation 3	Y”	Internal/External Rotation

* Prime [‘] and double prime [“] notations represent previously rotated axes due to the rotation of the local coordinate system resulting in all axes within that system being rotated. [Rotation about X axis also results in rotation of both Y and Z axes resulting in a new system of X’, Y’, Z’. Subsequent rotations are then about those axes.]

Design and Procedures

Athletic shorts and a loose-fitting t-shirt were worn by all participants to allow for unobstructed access to necessary anatomical landmarks for digitizing. Following sensor attachment and digitization, participants were allowed an unlimited amount of time to warm-up to acclimate to the testing procedures (Keeley et al., 2015). Once the participant self-declared they were ready to start the testing, they were instructed to throw three maximal effort fastballs to a catcher at the appropriate distance away, determined by the participant’s age/league (“Pitch Smart,” n.d.). For all test trials, pitches were delivered from the windup position. A pitch trial was saved if the ball was deemed a strike as determined by the Rapsodo®, ball flight analytics monitor.

All pitches were thrown from a 40 cm x 60 cm Bertec force plate (Bertec Corp., Columbus, OH, USA) built into the pitching surface. Force plate data were sampled at a rate of 1200 Hz. Prior to, and immediately following the pitching trials, participants will perform three SLS on the ipsilateral leg to their throwing arm. To perform the SLS, participants were required to cross their arms over their chest, flex the non-testing leg at the knee to 90°, placing the lower leg behind the body, then squat as low as possible while maintaining balance and then ascended to a neutral stance. Participants were allowed to practice prior to SLS testing (average practice time 1 minute). For the purpose of this study, LPHC stability was based on a method derived from previous studies (G. G. Gilmer et al., 2018, 2017; Huang et al., 2010). LPHC stability was based on the amount of total knee excursion (knee valgus) throughout the SLS range of motion (Bolgla & Malone, 2004; Claiborne et al., 2006; Crossley et al., 2011; DiMattia et al., 2005; Ford, Myer, & Hewett, 2003; Sigward, Ota, & Powers, 2008; Zeller et al., 2003). Knee valgus was measured using a modified version of previously described methods by Ford et al (Ford et al., 2003). Frontal plane total knee valgus was determined as the differences between the minimum value at initial stance and the maximum value of knee valgus during the decent phase and ascent phase of the SLS. Kinematic data were used to identify the knee angle, pitching events and phases within the pitching cycle. Kinetic variables of interest were shoulder (anterior/posterior, compression/distraction, abduction/adduction) and elbow anterior/posterior, compression/distraction, valgus/varus) maximum forces.

Data Analysis

Descriptive statistics were reported for all kinetic data for the fastest fastball for strikes by each participant. Data were averaged across the three trials of fastball pitches for strikes at two pitching events of shoulder maximum external rotation and ball release, and the three phases of arm cocking, arm acceleration and arm deceleration (Seroyer et al., 2010). Ball release was marked as the midpoint between shoulder maximal external and internal rotation (Oliver, Lohse, et al., 2015). Statistical analyses were performed using IBM SPSS Statistics 22 software (IBM Corp., Armonk, NY) for both normally and non-normally distributed data with an alpha level set *a priori* at $\alpha = 0.05$. Prior to analyses, all variables were checked for normal distributions employing a Shapiro-Wilk test for normality. Individual data points that are more than ± two standard deviations from the mean were not used for analysis. Correlation and regression analyses were conducted for Research Questions 1 and 2 to identify the strength of the relationships between SLS performance (knee valgus) and the following: pitching arm shoulder (anterior/posterior, compression/distraction, abduction/adduction) and elbow anterior/posterior, compression/distraction, valgus/varus) maximum forces normalized to body mass at maximum external rotation, ball release and peak values during the phases of arm cocking, arm acceleration, and arm deceleration. The regression technique was employed for statistically significant variables to define a model identifying the probability of a pitcher whom may be at risk of injury due to increased knee valgus during the SLS. For Research Questions 3 and 4, a correlational analysis was performed (Table 3). Correlational strengths were defined as follows: 0.20 – 0.39 weak; 0.40 – 0.59 moderate; and $\geq$ 0.60 strong.

Table 3. Correlation and Regression Analysis.

	Research Question (RQ)	Dependent Variable (DV)	Independent Variable (IV)	Event	Phases
RQ1	Is there a correlation between SLS performance and shoulder kinetics?	a. anterior/posterior force b. compression /distraction force c. abduction/adduction force	SLS performance (knee valgus)	a. maximum shoulder external rotation b. ball release	a. arm cocking b. arm acceleration c. arm deceleration
RQ2	Is there a correlation between SLS performance and elbow kinetics?	a. anterior/posterior force b. compression /distraction force c. varus/valgus force	SLS performance (knee valgus)	a. maximum shoulder external rotation b. ball release	a. arm cocking b. arm acceleration c. arm deceleration
RQ3	Is there a correlation between SLS performance and ball speed?	a. ball speed	SLS performance (knee valgus)	During pitching cycle	
RQ4	Is there a correlation between SLS performance and ball spin?	a. ball spin	SLS performance (knee valgus)	During pitching cycle	

CHAPTER 4

Results

The purpose of this project was to determine the correlation of LPHC stability via the single leg squat (SLS) to shoulder and elbow kinetics, and ball control (velocity and spin) during the fastball baseball pitch. This chapter describes and outlines the results from each research question:

RQ1: Is there a correlation between SLS performance (knee valgus) and shoulder kinetics (anterior/posterior, compressive/distraction, abduction/adduction forces) during baseball pitching?

RQ2: Is there a correlation between SLS performance (knee valgus) and elbow kinetics (anterior/posterior, compressive/distraction, valgus/varus forces) during baseball pitching?

RQ3: Is there a correlation between SLS performance (knee valgus) and ball speed during baseball pitching?

RQ4: Is there a correlation between SLS performance (knee valgus) and ball spin during baseball pitching?

Twenty-five right handed male baseball athletes volunteered to participate; single leg squat (SLS) performance was normally distributed for the lead leg (left) and stance leg (right) (Appendix F) (17.33 ± 3.05 years; 182.42 ± 9.18 cm; 78.62 ± 15.57 kg). Means and standard deviations for the SLS performance were a stance leg (right) degree of knee valgus of 15.7° ± 11.3° and lead leg (left) degree of knee valgus 11.1° ± 4.9°. Means and standard deviations for warm-up time were 06:18 ± 02:20 mins:secs. Descriptive statistics for shoulder and elbow kinetics at the two pitching events of shoulder maximum external rotation (MER), ball release (BR), and during the three phases of arm cocking, arm acceleration and arm deceleration are presented below (Tables 4 & 5).

Table 4. Means and standard deviations for shoulder kinetics

Pitching kinetic variable (N)	Mean ± standard deviation	*N*
Shoulder A/P forces at MER	31.2 ± 162.4	25
Shoulder A/P forces at BR	-155.0 ± 403.7	25
Shoulder D/C forces at MER	-39.5 ± 187.1	25
Shoulder D/C forces at BR	-108.8 ± 157.1	25
Shoulder AB/ADD forces at MER	-130.1 ± 267.2	25
Shoulder AB/ADD forces at BR	-255.4 ± 193.1	25
Cocking: Shoulder A/P	143.8 ± 160.6	25
Cocking: Shoulder D/C	-35.1 ± 191.2	25
Cocking: Shoulder AB/ADD	-131.5 ± 307.8	25
Accel: Shoulder A/P	-98.4 ± 523.0	25
Accel: Shoulder D/C	-202.9 ± 267.2	25
Accel: Shoulder AB/ADD	-349.7 ± 350.0	25
Decel: Shoulder A/P	-256.2 ± 428.9	25
Decel: Shoulder D/C	-210.4 ± 271.5	25
Decel: Shoulder AB/ADD	-223.7 ± 276.9	25

A/P=anterior(+)/posterior(-); D/C= distraction(+)/compression(-); AB/ADD=abduction(+)/adduction(-); Cocking= cocking phase; Accel=acceleration phase; Decel=deceleration phase

Table 5. Means and standard deviations for elbow kinetics variables

Pitching kinetic variable (N)	Mean ± standard deviation	*N*
Elbow A/P forces at MER	29.4 ± 116.9	25
Elbow A/P forces at BR	-45.9 ± 98.4	25
Elbow D/C forces at MER	100.1 ± 159.2	25
Elbow D/C forces at BR	275.5 ± 226.9	25
Elbow VA/VG forces at MER	-87.3 ± 92.7	25
Elbow VA/VG forces at BR	-117.9 ± 142.9	25
Cocking: Elbow A/P	40.7 ± 124.4	25
Cocking: Elbow D/C	111.8 ± 167.4	25
Cocking: Elbow VA/VG	-81.9 ± 109.9	25
Accel: Elbow A/P	4.1 ± 200.7	25
Accel: Elbow D/C	374.1 ± 286.1	25
Accel: Elbow VA/VG	-176.1 ± 191.1	25
Decel: Elbow A/P	-99.2 ± 172.1	25
Decel: Elbow D/C	342.2 ± 223.3	25
Decel: Elbow VA/VG	-153.8 ± 189.1	25

A/P=anterior(+)/posterior(-); D/C= distraction(+)/compression(-);VA/VG=varus(+)/valgus(-); Cocking= cocking phase; Accel=acceleration phase; Decel=deceleration phase

Research Question 1: Relationship of SLS performance to shoulder kinetics during the baseball pitch

Measurements of shoulder kinetics (anterior/posterior force (X), distraction/compression force (Y) and abduction/adduction force (Z)) were examined at the time points of maximum external rotation (MER), ball release (BR) also during the cocking, acceleration and deceleration phase during the baseball pitch.

Correlation and multiple regression analyses, for statistically significant variables, were conducted to examine the relationship of shoulder kinetics to SLS performance. Shoulder kinetics (anterior/posterior force, compression /distraction force, and abduction/adduction force) were the dependent variables for the statistical test. Statistical results, correlation graphs and regression analyses for data with a statistically significant Spearman rho (ρ) correlation for the stance leg are presented below (Table 6).

Table 6. Spearman rho (ρ) and significance for shoulder kinetics on stance leg (r)

	Time point / Phase	**Pitching kinetic variable (N)**	**ρ**	***Sig.***
Stance Leg (R)	*MER*	*Anterior/Posterior*	0.06	0.76
	BR	*Anterior/Posterior*	-0.05	0.77
	MER	*Distraction/Compression*	0.08	0.67
	BR	*Distraction/Compression*	0.22	0.29
	MER	*Abduction/Adduction*	-0.05	0.81
	BR	*Abduction/Adduction*	0.18	0.39
	Cocking	*Anterior/Posterior*	0.15	0.46
	Cocking	*Distraction/Compression*	0.11	0.60
	Cocking	*Abduction/Adduction*	0.07	0.73
	Acceleration	*Anterior/Posterior*	-0.09	0.65
	Acceleration	*Distraction/Compression*	0.10	0.63
	Acceleration	*Abduction/Adduction*	-0.03	0.86
	Deceleration	*Anterior/Posterior*	0.18	0.39
	Deceleration	*Distraction/Compression*	0.12	0.57
	Deceleration	*Abduction/Adduction*	-0.00	0.99

R,r=right; L,l=left

Statistical results, correlation graphs and regression analyses for data with a statistically significant Spearman rho (ρ) correlation for the lead leg are presented below (Table 7).

Table 7. Spearman rho (ρ) and significance for shoulder kinetics on lead leg (l)

	Time point / Phase	**Pitching kinetic variable (N)**	**ρ**	***Sig.***
Lead Leg (L)	*MER*	*Anterior/Posterior*	-0.05	0.80
	BR	*Anterior/Posterior*	-0.16	0.44
	MER	*Distraction/Compression*	0.23	0.26
	BR	*Distraction/Compression*	0.17	0.42
	MER	*Abduction/Adduction*	-0.17	0.41
	BR	*Abduction/Adduction*	-0.10	0.62
	Cocking	*Anterior/Posterior*	-0.04	0.82
	Cocking	*Distraction/Compression*	0.03	0.14
	Cocking	*Abduction/Adduction*	-0.12	0.56
	Acceleration	*Anterior/Posterior*	-0.09	0.64
	Acceleration	*Distraction/Compression*	0.36	0.07
	Acceleration	*Abduction/Adduction*	0.00	0.98
	Deceleration	*Anterior/Posterior*	0.14	0.49
	Deceleration	*Distraction/Compression*	-0.11	0.60
	Deceleration	*Abduction/Adduction*	-0.11	0.61

R,r=right; L,l=left

The results revealed a statistically insignificant association between SLS performance on the stance leg at the event of BR and on the lead leg at the events of MER and during the acceleration phase (Table 6 and 7). SLS performance for the stance leg resulted in a weak positive relationship between compressive forces at BR. While, SLS performance for the lead leg resulted in a weak positive relationship between the compressive forces at MER and during the acceleration phase.

Research Question 2: Relationship of SLS performance to elbow kinetics during the baseball pitch

Measurements of elbow kinetics (anterior/posterior force (X), distraction/compression force (Y) and varus/valgus force (Z)) were examined at the time points of maximum external rotation (MER), ball release (BR) and during the cocking, acceleration and deceleration phase during the baseball pitch.

Correlation and multiple regression analyses, for statistically significant variables, were conducted to examine the relationship of elbow kinetics to SLS performance. Statistical results, correlation graphs and regression analyses for data with a statistically significant Spearman rho (ρ) correlation for the stance leg are presented below (Table 8).

Table 8. Spearman rho (ρ) and significance for elbow kinetics on stance leg (r)

	Time point / Phase	**Pitching kinetic variable (N)**	**ρ**	***Sig.***
Stance Leg (R)	*MER*	*Anterior/Posterior*	-0.10	0.61
	BR	*Anterior/Posterior*	-0.31	0.12
	MER	*Distraction/Compression*	0.15	0.46
	BR	*Distraction/Compression*	-0.08	0.69
	MER	*Varus/Valgus*	-0.21	0.32
	BR	*Varus/Valgus*	0.11	0.59
	Cocking	*Anterior/Posterior*	-0.09	0.65
	Cocking	*Distraction/Compression*	-0.04	0.83
	Cocking	*Varus/Valgus*	-0.23	0.27
	Acceleration	*Anterior/Posterior*	-0.32	0.12
	Acceleration	*Distraction/Compression*	-0.04	0.82
	Acceleration	*Varus/Valgus*	0.08	0.67
	Deceleration	*Anterior/Posterior*	-0.05	0.78
	Deceleration	*Distraction/Compression*	-0.21	0.31
	Deceleration	*Varus/Valgus*	0.16	0.43

R,r=right; L,l=left

Statistical results, correlation graphs and regression analyses for data with a statistically significant Spearman rho (ρ) correlation for the lead leg are presented below (Table 9).

Table 9. Spearman rho (ρ) and significance for elbow kinetics on lead leg (l)

	Time point / Phase	**Pitching kinetic variable (N)**	**ρ**	***Sig.***
Lead Leg (L)	*MER*	*Anterior/Posterior*	-0.12	0.55
	BR	*Anterior/Posterior*	0.18	0.38
	MER	*Distraction/Compression*	0.19	0.36
	BR	*Distraction/Compression*	0.15	0.48
	MER	*Varus/Valgus*	-0.04	0.83
	BR	*Varus/Valgus*	0.02	0.89
	Cocking	*Anterior/Posterior*	0.04	0.84
	Cocking	*Distraction/Compression*	0.08	0.68
	Cocking	*Varus/Valgus*	-0.02	0.90
	Acceleration	*Anterior/Posterior*	0.05	0.80
	Acceleration	*Distraction/Compression*	-0.10	0.61
	Acceleration	*Varus/Valgus*	-0.05	0.81
	Deceleration	*Anterior/Posterior*	0.21	0.30
	Deceleration	*Distraction/Compression*	-0.02	0.90
	Deceleration	*Varus/Valgus*	-0.12	0.58

R,r=right; L,l=left

The results revealed a statistically insignificant association was found between SLS performance on the stance leg at the event of MER and during cocking and acceleration phases and for the lead leg during the deceleration phase (Table 8 and 9). SLS performance for the stance leg resulted in a weak negative relationship between valgus forces at MER and cocking; also a weak positive between anterior forces during acceleration. SLS performance for the lead leg resulted in a weak positive relationship between the posterior forces during the deceleration

Research Question 3: Relationship of SLS performance to ball speed during the baseball pitch

Measurements of ball speed were taken after BR during the pitching cycle. Correlation and multiple regression analyses were conducted to examine the relationship of SLS performance to ball speed. Descriptive statistics and statistical results are presented below (Tables 10-12). No statistically significant relationship was found between SLS performance on the stance leg and ball speed (ρ = -.13, p = .520) (Figure 5) nor on the lead leg and ball speed (ρ = .18, p = .399) (Figure 6). The multiple regression model with one predictor produced: R^2 = 0.03; $F_{(1,24)}$ = 0.005; p = 0.84 for the stance leg and R^2 = 0.01; $F_{(1,24)}$ = 1.19; p = 0.29 for the lead leg.

Model: Ball speed = 63.5 + .001 * stance leg (degree of knee valgus)

Model: Ball speed = 65.4 + .180 * lead leg (degree of knee valgus)

Therefore, stance leg knee valgus and lead leg degree of knee valgus were not significant predictors of ball speed in the multiple regression model. Thus, rendering a result that SLS performance had no relationship with ball speed.

Table 10. Means and standard deviations for ball speed

	Mean ± standard deviation	***N***
Ball Speed (mph)	63.4 ± 25.2	25
Stance Leg Valgus (deg)	-15.7 ± 11.3	25
Lead Leg Valgus (deg)	-11.1 ± 4.9	25

Table 11. Multiple Regression model for ball speed (Stance Leg)

	B	**B**	**Sig.**
Ball Speed (mph)	63.53		
Stance Leg Valgus (deg)	.00	-.016	.946

Table 12. Multiple Regression model for ball speed (Lead leg)

	B	B	Sig.
Ball Speed (mph)	65.47		
Lead Leg Valgus (deg)	.180	.256	.290

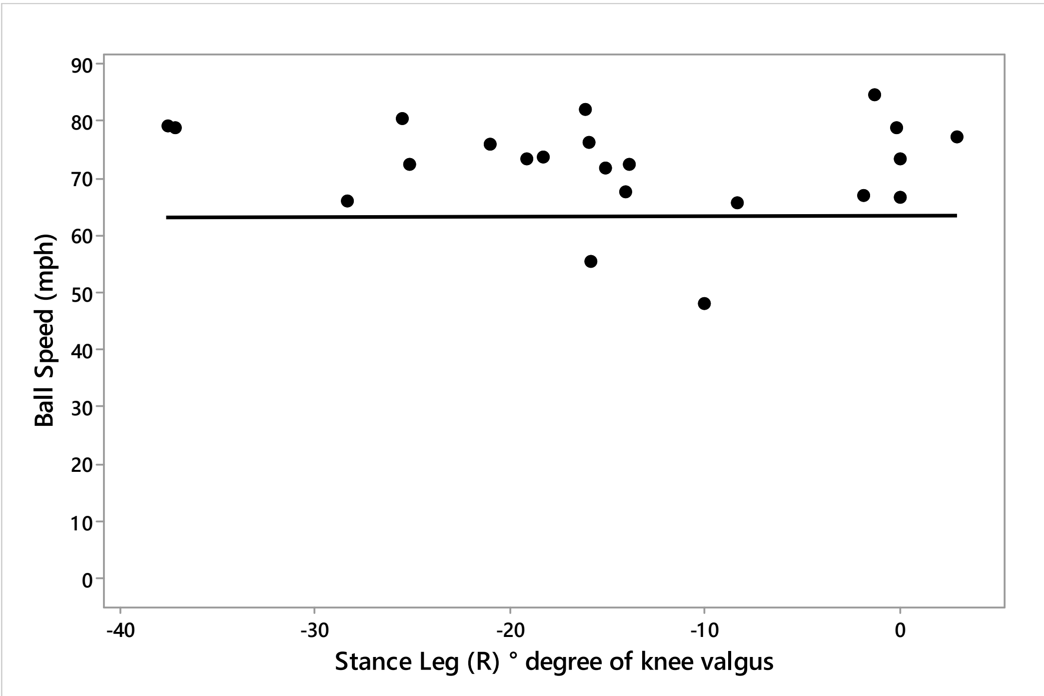


Figure 5. Correlation of stance leg degree of knee valgus to ball speed.

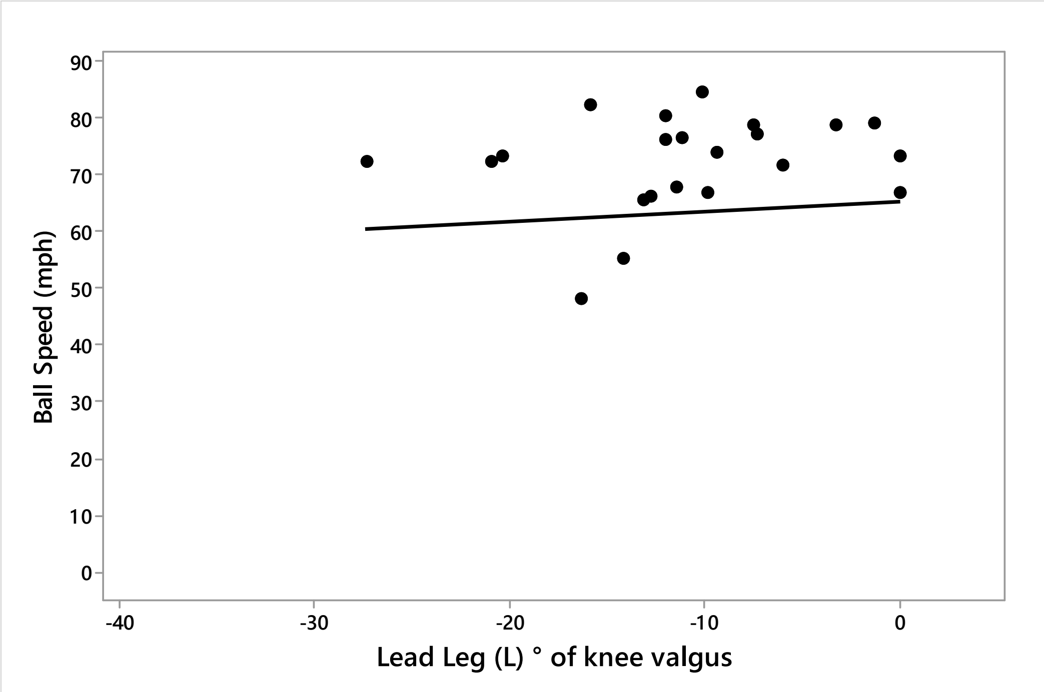


Figure 6. Correlation of lead leg degree of knee valgus to ball speed.

Research Question 4: Relationship of SLS performance to ball spin during the baseball pitch

Measurements of ball spin were taken after ball release during the pitching cycle. Correlation and multiple regression analyses were conducted to examine the relationship of SLS performance to ball spin. Descriptive statistics and statistical results are presented below (Tables 13-15). No statistically significant relationship was found between the degree of knee valgus on the stance leg and ball spin (ρ = -.21, *p* = .30) (Figure 7) nor on the lead leg and ball spin (ρ = .15, *p* = .46) (Figure 8). The multiple regression model with one predictor produced: R^2 = 0.04; $F_{(1,24)}$ = 4.90; *p* = .302 for the stance leg and R^2 = 0.02; $F_{(1,24)}$ = 0.00; *p* = 0.983 for the lead leg.

Model: Ball spin = 1452.0 – 3.84 * stance leg (degree of knee valgus)

Model: Ball spin = 1541.0 + 2.89 * lead leg (degree of knee valgus)

Therefore, stance leg degree of knee valgus and lead leg degree of knee valgus were not a predictor in the multiple regression model. Resulting in no relationship between SLS performance and ball spin for both the stance and lead legs.

Table 13. Means and standard deviations for ball spin

	Mean ± standard deviation	**N**
Ball Spin (rpm)	1508.9 ± 612.7	25
Stance Leg Valgus (deg)	-15.7 ± 11.3	25
Lead Leg Valgus (deg)	-11.1 ± 4.9	25

rpm – revolutions per minute

Table 14. Multiple Regression model for ball spin (Stance Leg)

	B	**β**	**Sig.**
Ball Spin (rpm)	1452.0		
Stance Leg Valgus (deg)	-3.84	-.485	.302

Table 15. Multiple Regression model for ball spin (Lead leg)

	B	**β**	**Sig.**
Ball Spin (rpm)	1541.0		
Lead Leg Valgus (deg)	2.89	.006	.983

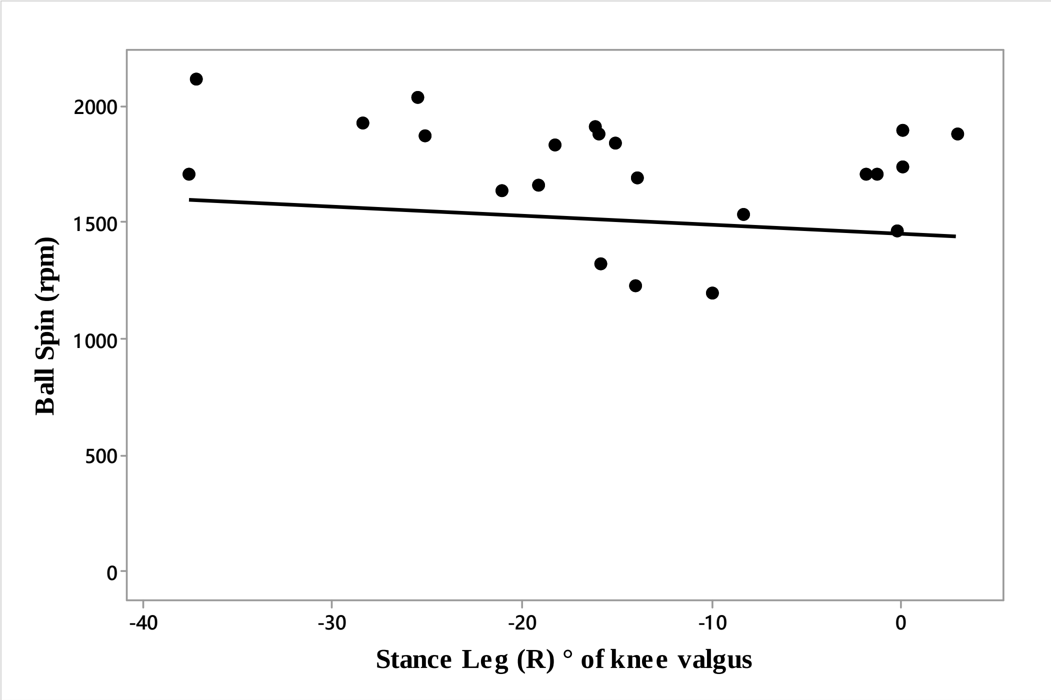


Figure 7. Correlation of stance leg degree of knee valgus to ball spin.

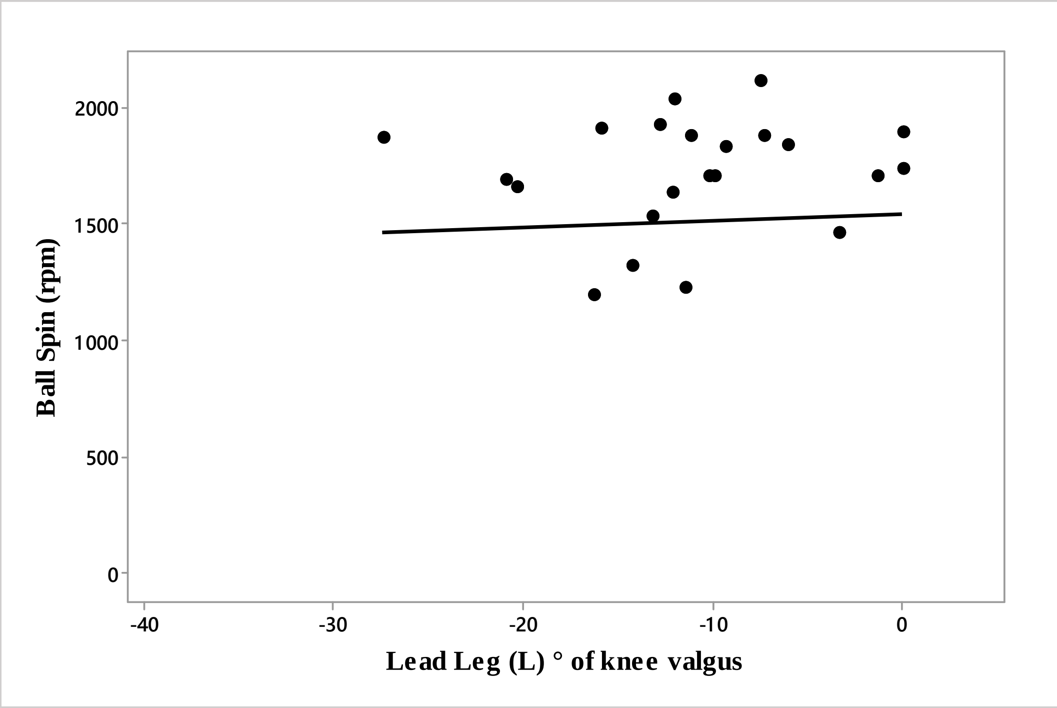


Figure 8. Correlation of lead leg degree of knee valgus to ball spin.

CHAPTER 5

Discussion

The purpose of this study was to investigate the correlation of lumbopelvic-hip complex (LPHC) stability via the single leg squat (SLS) to peak shoulder and elbow kinetics, as well as ball control parameters (velocity and spin) during the fastball baseball pitch. This chapter is divided by the four research questions and addresses the applications of these findings to baseball pitchers.

Research Question 1: Is there a correlation between SLS performance (knee valgus) and shoulder kinetics (anterior/posterior, compressive/distraction, abduction/adduction forces) during baseball pitching?

It was hypothesized that shoulder kinetics (anterior/posterior, compressive/distraction, abduction/adduction forces) would be negatively correlated with SLS performance (knee valgus) during the baseball pitch. The results of the current study did not support our hypothesis of a negative relationship between SLS performance and shoulder kinetics during the baseball pitch (Table 16).

Table 16. H01: Spearman Correlation Coefficient (ρ) and significance for shoulder kinetics

	Time point / Phase	**Pitching kinetic variable (N)**	**ρ**	***Sig.***
Stance Leg (R)	*BR*	*Anterior/Posterior*	-0.05	0.77
	MER	*Abduction/Adduction*	-0.05	0.81
	Acceleration	*Anterior/Posterior*	-0.09	0.65
	Acceleration	*Abduction/Adduction*	-0.03	0.86
	Deceleration	*Abduction/Adduction*	-0.00	0.99
Lead Leg (L)	*MER*	*Anterior/Posterior*	-0.05	0.80
	BR	*Anterior/Posterior*	-0.16	0.44
	MER	*Abduction/Adduction*	-0.17	0.41
	BR	*Abduction/Adduction*	-0.10	0.62
	Cocking	*Anterior/Posterior*	-0.04	0.82
	Cocking	*Abduction/Adduction*	-0.12	0.56
	Acceleration	*Anterior/Posterior*	-0.09	0.64
	Deceleration	*Distraction/Compression*	-0.11	0.60
	Deceleration	*Abduction/Adduction*	-0.11	0.61

The results reported in this study indicate no statistically significant relationships were found between the degree of knee valgus on the stance leg nor lead leg for shoulder kinetics. Therefore, in the current study, there is no relationship between SLS performance and shoulder kinetics.

The baseball pitch is a dynamic upper extremity movement and the contributions of each segment to optimal energy transfer from the most proximal of the lower extremity to the most distal of the upper extremity is dependent upon segmental stability and mobility. The ability of the upper extremity to function efficiently depends upon the LPHC to provide proximal stability for distal mobility, as well as to generate the forces and energy necessary to perform dynamic overhead movements such as baseball pitching. With the LPHC serving as the direct link in the transfer of energy from the lower extremity to the upper extremity, research has focused on the examination of LPHC stability and mobility though the SLS assessment (Chaudhari et al., 2011; Claiborne et al., 2006; Crossley et al., 2011; DiMattia et al., 2005; Zeller et al., 2003). In addition, there has been attention on the influence of LPHC stability to shoulder and elbow kinematics and kinetics in overhead throwing (Chaudhari et al., 2011, 2014; G. G. Gilmer et al., 2018; Keeley et al., 2015; K.G. Laudner, Wong, & Meister, 2018; Oliver, 2014; Oliver & Keeley, 2010a; Oyama et al., 2013; Plummer, Oliver, Powers, & Michener, 2018). Based on the direct association of LPHC stability and upper extremity kinematics and kinetics, researchers have encouraged training and rehabilitation programs to implement LPHC stability regimens in an attempt to curtail the incidence of upper extremity injury (Chaudhari et al., 2011, 2014; Keeley et al., 2015; K.G. Laudner et al., 2018; Oyama et al., 2013; Plummer et al., 2018). Dynamic knee valgus is an indicator of instability and research has shown that diminished LPHC control has a negative effect on pitching performance (Chaudhari et al., 2011, 2014; Saeterbakken, van den Tillaar, & Seiler, 2011). With the known relationship between the LPHC and the upper extremity, this current study aimed to examine the association between SLS performance to upper extremity kinetics and ball control parameters.

The lack of association between LPHC stability as indicated by knee valgus during the SLS and shoulder kinetics in the current study is somewhat surprising. Previously, it has been reported that LPHC instability is associated with altered pitching performance, specifically greater trunk lean has been related to increased shoulder kinetics. Plummer et al. reported that those with decreased SLS performance displayed greater trunk lean during the pitching motion. The authors only considered trunk movement during the LPHC assessment and did not consider knee valgus. In light of this, it is tempting to conclude that while trunk stability as assessed with the SLS is a predictor of shoulder kinetics, in the current study knee valgus of the stance leg, is not (Plummer et al., 2018). Laudner et al. also examined LPHC stability via a SLS and pitching mechanics and found a significant relationship between SLS performance on the stance leg and shoulder horizontal torque. However, no relationship was found between SLS performance on the lead leg and shoulder kinetics; similar to the results of the current study (Laudner et al., 2018).

The aforementioned studies examined LPHC stability via the SLS and revealed strong relationships between LPHC instability and increased shoulder kinetics. Though the current study found no relationship, the variability in SLS variables used to indicate LPHC stability indicates the need for further investigation into SLS assessment and shoulder kinetics in baseball pitching.

Research Question 2: Is there a correlation between SLS performance (knee valgus) and elbow kinetics (anterior/posterior, compressive/distraction, valgus/varus forces) during baseball pitching?

It was hypothesized that elbow kinetics (anterior/posterior, compressive/distraction, valgus/varus forces) would be negatively correlated with SLS performance (knee valgus) during the baseball pitch.

Table 17. H02: Spearman Correlation Coefficient (ρ) and significance for elbow kinetics

	Time point / Phase	**Pitching kinetic variable (N)**	**ρ**	***Sig.***
Stance Leg (R)	*MER*	*Anterior/Posterior*	-0.10	0.61
	BR	*Anterior/Posterior*	-0.31	0.12
	BR	*Distraction/Compression*	-0.08	0.69
	MER	*Varus/Valgus*	-0.21	0.32
	Cocking	*Anterior/Posterior*	-0.09	0.65
	Cocking	*Distraction/Compression*	-0.04	0.83
	Cocking	*Varus/Valgus*	-0.23	0.27
	Acceleration	*Anterior/Posterior*	-0.32	0.12
	Acceleration	*Distraction/Compression*	-0.04	0.82
	Deceleration	*Anterior/Posterior*	-0.05	0.78
	Deceleration	*Distraction/Compression*	-0.21	0.31
Lead Leg (L)	*MER*	*Anterior/Posterior*	-0.12	0.55
	MER	*Varus/Valgus*	-0.04	0.83
	Cocking	*Varus/Valgus*	-0.02	0.90
	Acceleration	*Distraction/Compression*	-0.10	0.61
	Acceleration	*Varus/Valgus*	-0.05	0.81
	Deceleration	*Distraction/Compression*	-0.02	0.90
	Deceleration	*Varus/Valgus*	-0.12	0.58

The results reported in this study indicate no statistically significant relationships were found between the degree of knee valgus on the stance leg nor lead leg for elbow kinetics. Therefore, in the current study, there is no relationship between SLS performance and elbow kinetics. The results of the current study are not in agreement with our hypothesis (Table 17).

The significance of LPHC stability has been well established in baseball pitching, however the influence of LPHC stability via the SLS and elbow kinetics is lacking. Of the literature regarding SLS and baseball pitching, only one to the author's knowledge examines elbow kinetics. Laudner et al. examined LPHC stability via bilateral SLS among NCAA Division I and professional minor league pitchers. It was found that stance leg SLS performance was significantly related to elbow valgus torque, while there were no significant relationships between lead leg SLS performance and elbow kinetics. Laudner's findings are not in agreement with the current study. As the current study revealed no relationships in the lead and stance leg versus SLS performance. The fact that both studies are in contrast to each other regarding SLS performance and elbow kinetics warrants the need for further investigations into LPHC stability.

Weakness or failure of the LPHC has been associated with dysfunction at proximal and distal segments of the kinetic chain (Burkhart, et al., 2003; Chu et al., 2016; W.B. Kibler et al., 2006). The decreased compressive force at the event of MER is ideal in that typically at MER the elbow sustains the greatest valgus force resulting in increased compression on the lateral aspect (Anz et al., 2010). Though there was no relationship between valgus/varus kinetics about the elbow the decreased compression could prove beneficial in curtailing long term injury susceptibility. Specific injuries at the elbow have been linked to numerous kinetic variables throughout the pitching cycle; specifically, ulnar collateral ligament sprains due to excessive elbow valgus torques and shoulder external rotation torques during the cocking phase, however, there has not been any literature to date relating posterior elbow forces during the deceleration phase. While shoulder injuries have been linked to labrum and rotator cuff injuries occurring due to the distraction forces during the deceleration phase (Escamilla et al., 2007; Fleisig, Andrews, Dillman, & Escamilla, 1995b; Fleisig, Barrentine, Escamilla, & Andrews, 1996b; Fleisig et al., 1999; Werner et al., 2001).

With the known importance of the kinetic chain during the throwing motion, any disruptions within the chain can result in decreased overhead throwing performance and subsequently increasing the risk of injury (Laudner et al., 2018). To reduce the risk of injury to the upper extremity, LPHC strengthening has been suggested to improve performance during overhead throwing, which could subsequently also play a role in decreasing the forces placed on the shoulder and elbow during the baseball pitch (Oliver, Weimar, et al., 2015). Exercises to maintain balance and proprioception have been suggested to address the relationship between upper extremity kinetics and LPHC control. Control needed to achieve unilateral support on the stance leg during the baseball pitch is often regulated by the gluteus medius (Dillman et al., 1993; Oliver, Weimar, et al., 2015; Weber et al., 2014). It is worth noting this muscle's role because baseball pitchers require a large amount of gluteal activity throughout the baseball pitch especially in the back leg where gluteal activity peaks during the acceleration phase (Oliver & Keeley, 2010a; Plummer & Oliver, 2014). With the significance of the gluteals during the pitching motion, strengthening alone cannot overcome poor LPHC control. The results of this study suggest using a unilateral stance LPHC motion, closely related to our test, can be used by clinicians to improve LPHC control during the throwing motion to reduce the stresses to the upper extremity.

Future investigations into the use of trunk lean may also be of value in determining the shoulder forces during pitching. Pitching is complex activity that required the transfer of energy from the legs, through the trunk, to the upper extremity (Kibler et al., 2006; Putnam, 1993). With 50% of the kinetic energy contributed from the hips and trunk, trunk stability during the pitching cycle is important for postural control (Byrum et al., 2010). Previous studies have identified a contralateral trunk lean (away from throwing side) of 10° minimizes the stresses to the upper extremity (Matsuo et al., 2006). In support, Oyama et al. and Solomito et al. found the same results but in high school and collegiate pitchers, respectively (Oyama et al., 2013). Due to pitching being a high-speed task, identifying abnormal trunk motion may be difficult. In a recent study by Plummer et al. the author's purpose was to determine the relationship between the degree of lateral trunk lean during pitching and if it can be predicted using a clinical screening test, SLS, to identify pitchers with impaired trunk motion during the baseball pitch. It was revealed that lateral trunk lean during the SLS is able to predict the amount of trunk lean during the pitching (Plummer et al., 2018). The above studies support the importance of trunk stability during the baseball pitch.

As lateral trunk lean has been identified as a precursor to increased shoulder and elbow kinetics contribution to injury, use of the naked eye in identifying persons with altered trunk abnormalities may be difficult due to the high-speed dynamic nature pitching presents. Implementing a screening tool can help a clinician identify those at risk of movement deficits in their pitching mechanics.

The ballistic nature of the baseball pitch requires proper timing and the coordination of lower extremity, trunk, and upper extremity movements; thus, the need for an efficient kinetic chain is important. The critical link in the kinetic chain that allows for efficient energy transfer from the lower extremity to the upper extremity is the lumbopelvic-hip complex (LPHC). The LPHC encompasses the large muscles of the hips and pelvis that stabilize the lower extremity and are able to generate substantial amounts of force and power to the upper extremity and thought to play an integral role in both accelerating and decelerating the upper body. When the stability of the lower extremity is compromised, specifically the degree of knee valgus, there is a disruption in normal functioning of the kinetic chain thereby predisposing the upper extremity to increased injury susceptibility as well as a decrease in performance outcomes.

Research Question 3: Is there a correlation between SLS performance (knee valgus) and ball speed during baseball pitching?

The author hypothesized that greater ball speed would be positively correlated with SLS performance (knee valgus). A positive correlation between lead leg SLS performance and ball speed was found. As SLS performance (degree of knee valgus) decreased for the lead leg, the participant had increased ball speed. These results are in agreeance with previous literature examining pitching performance and LPHC control. Chaudhari et al. investigated in-game pitching performance in 75 healthy Minor-league baseball pitchers. The authors defined pitching performance by the number of innings pitched during a season and compared them to injuries sustained during that same season. It was found that those with increased LPHC control had fewer walks and hits per inning than those with decreased LPHC control (Chaudhari et al., 2011). In contrast to the literature, Gilmer et al. assessed LPHC instability to find that amongst specific group of softball athletes, SLS performance may not accurately be an indicator of pitching performance (G. Gilmer, Washington, & Oliver, 2018).

In baseball pitching, increasing ball velocity is the overarching goal for every pitch. Pitchers who are able to throw the fastest while still maintaining command of the strike zone (striking out pitchers), suggests that a successful pitch depends on energy generation from the legs. This energy must be transferred from the lower extremity through the body to the throwing hand, theoretically requiring optimal lumbopelvic control (Putnam, 1993).

Research Question 4: Is there a correlation between SLS performance (knee valgus) and ball spin during baseball pitching?

The author hypothesized that greater ball spin would be positively correlated with SLS performance (knee valgus); however, no relationship was found. The multiple regression model determined that the stance leg degree of knee valgus was not a predictor of ball spin. Resulting in SLS performance was not a predictor of ball spin on either leg.

Identifying individuals at increased risk of injury would be advantageous in preventing days missed from playing; Chaudhari et al. investigated the notion that professional pitchers with poor LPHC were more likely to miss 30+ days of spring training. The author concluded that poor LPHC control in professional pitchers was associated with increased risk of missing significant time from the field of play (Chaudhari et al., 2014). To the author's knowledge, there have been no formal investigations into the effect of ball spin on the kinetics to the upper extremities. The current study results are in agreeance that poor LPHC control as a risk factor for time missed in baseball pitchers.

A baseball pitcher's ability to maximize ball speed and variability in movement while avoiding shoulder and elbow injuries is an important determinant of a successful career. The throwing motion requires coordination and activation of the muscles and joints from both the upper and lower extremities to maximize performance and reduce the risk of injury. It is known that efficient utilization of the kinetic chain, specifically the lower extremity, in pitching has been shown to decrease the risk of injury (Chu et al., 2016; Guido, Werner, & Meister, 2009; Oliver, 2014; Oliver & Plummer, 2011; Oliver et al., 2016; Robb et al., 2010) as well as influence pitching performance (Chaudhari, et al., 2011; Chaudhari, et al., 2014).

CHAPTER 6

Conclusion

. The results of the current study indicated that SLS performance had: (1) no relationship with shoulder kinetics, (2) no relationship with elbow kinetics, (3) no relationship with ball speed, and (4) no relationship with ball spin; concluding that LPHC stability had no influence on upper extremity kinetics for the current study. These findings suggest the need for further investigation into functional LPHC stability in throwing athletes in an attempt to assist clinicians during the evaluating process attempting to assist with identifying those persons whom may be at risk for upper extremity injuries; also for coaches who may be interested in predictors of performance.

Ultimately, the LPHC's role in throwing is to maintain stability for efficient energy transfer from the lower extremity to the upper extremity. Any interruption in one segment of the kinetic chain will alter the system during dynamic movements, which places extra stress on adjacent segments. Through LPHC instability, energy can be lost, as studies have found that a 20% reduction in energy generation from the lumbopelvic-hip complex (LPHC) during overhead throws leads to a 34% increase in load on the shoulder. As a means of quantifying LPHC stability, the single leg squat (SLS) has been used as a clinical tool to identify weaknesses in the LPHC musculature. Studies have shown that when performing a SLS, unstable athletes display a relatively high degree of knee valgus when compared to stable athletes. The mechanics of the baseball pitch creates large forces that are not restricted to the shoulder alone but rather imparted across all the anatomical joints involved in the throwing motion. Forces to the upper extremity may be greater in an athlete who is compensating for deficits within the kinetic chain. The most common baseball pitching injuries involving the rotator cuff; however, the dramatic rise in ulnar collateral ligament injuries have received much attention throughout the baseball community among high school pitchers. The ability of the upper extremity to function efficiently depends upon the LPHC to provide proximal stability for distal mobility, as well as to generate the forces and energy necessary to perform overhead throwing tasks. The ballistic nature of the baseball pitch requires proper timing and the coordination of lower extremity, trunk, and upper extremity movements; thus, the need for an efficient kinetic chain is important. The critical link in the kinetic chain that allows for efficient energy transfer from the lower extremity to the upper extremity is the lumbopelvic-hip complex (LPHC). The muscles of the LPHC aid in stabilization of the lower extremity and are able to generate substantial amounts of force and power to the upper extremity and thought to play an integral role in both accelerating and decelerating the upper body.

The LPHC plays a major role within the kinetic chain as well as providing a vital element of energy transfer from the lower to upper extremity in throwing. When the stability of the lower extremity is compromised, specifically the degree of knee valgus, there is a disruption in normal functioning of the kinetic chain thereby predisposing the upper extremity to increased injury susceptibility as well as a decrease in performance outcomes. With the known importance of the LPHC in dynamic overhead movements, the ability to classify LPHC stability becomes vital. The results of this study aimed to provide insight into the lack of data examining functional LPHC stability and its relationship on upper extremity kinetics in overhead athletes.

Future studies should consider examining knee and trunk kinematics when performing a single leg squat in the frontal and sagittal planes; to include individuals with upper extremity dysfunctions; as well as incorporate women baseball pitchers. The inclusion of those with upper extremity dysfunctions as well as women baseball pitchers could add to the literature concerning the physical attributes of those who suffer from dysfunction, and the attributes needed to make both men and women successful baseball pitchers. Furthermore, establishing LPHC parameters, specifically for the single leg squat, would aid in continuity when evaluating patients.

REFERENCES

Aguinaldo, A. L., Buttermore, J., & Chambers, H. (2007). Effects of upper trunk rotation on shoulder Joint torque among baseball pitchers of various levels. *Journal of Applied Biomechanics*, *23*, 42–51.

American Academy of Orthopedic Surgeons. (1995). Elbow enjuries in the throwing athleteâ□”OrthoInfoâ□”AAOS. Retrieved February 21, 2018, from https://orthoinfo.aaos.org/en/diseases--conditions/elbow-injuries-in-the-throwing-athlete/

Andrews, J. R., & Fleisig, G. S. (1998). Preventing throwing injuries. *Journal of Orthopaedic & Sports Physical Therapy*, *27*(3), 187–188. https://doi.org/10.2519/jospt.1998.27.3.187

Anz, A. W., Bushnell, B. D., Griffin, L. P., Noonan, T. J., Torry, M. R., & Hawkins, R. J. (2010). Correlation of torque and elbow injury in professional baseball pitchers. *The American Journal of Sports Medicine*, *38*(7), 1368–1374. https://doi.org/10.1177/0363546510363402

Beardsley, C. (2015, October 17). Biomechanics definitions. Retrieved July 16, 2018, from Strength & Conditioning Research website: https://www.strengthandconditioningresearch.com/biomechanics/biomechanics-definitions/

Blazevich, A. J. (2017). *Sports Biomechanics: The basics: optimising human performance*. Bloomsbury Publishing.

Bolgla, L. A., & Malone, T. R. (2004). Plantar fasciitis and the windlass mechanism: A biomechanical link to clinical practice. *Journal of Athletic Training*, *39*(1), 77. Retrieved from http://search.proquest.com/openview/061101aad99efce535d5527022d9a037/1?pq-origsite=gscholar&cbl=47878

Braun, S., Kokmeyer, S., & Millett, P. J. (2009). Shoulder injuries in the throwing athlete: *The Journal of Bone and Joint Surgery-American Volume*, *91*(4), 966–978. https://doi.org/10.2106/JBJS.H.01341

BSEMS. (2018). Overhead Athletes. Retrieved October 11, 2018, from Upper Limb Problems in Overhead Athletes website: http://www.bsems.com.au/overhead-athletes.html

Bunn, J. W. (1972). *Scientific principles of coaching*. Prentice-Hall.

Burkhart, S. S., Morgan, C. D., & Kibler, W. B. (2003). The disabled throwing shoulder: Spectrum of pathology part III: the SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy: Journal of Arthroscopic & Related Surgery*, *19*(6), 641–661.

Byrum, I., Bushnell, B., Dugger, K., Charron, K., Harrell, F., & Noonan, T. (2010). Preseason shoulder strength measurements in professional baseball pitchers: Identifying players at risk for injury. *American Journal of Sports Medicine*, *38*(7), 1375–1382.

Caine, D. J. (2010). Are kids having a rough time of it in sports? *British Journal of Sports Medicine*, *44*(1), 1–3. https://doi.org/10.1136/bjsm.2009.069484

Campbell, B. M., Stodden, D. F., & Nixon, M. K. (2010). Lower extremity muscle activation during baseball pitching. *The Journal of Strength & Conditioning Research*, *24*(4), 964–971. https://doi.org/10.1519/JSC.0b013e3181cb241b

Chalmers, P. N., Wimmer, M. A., Verma, N. N., Cole, B. J., Romeo, A. A., Cvetanovich, G. L., & Pearl, M. L. (2017). The Relationship Between Pitching Mechanics and Injury: A review of current concepts. *Sports Health: A Multidisciplinary Approach*, *9*(3), 216–221. https://doi.org/10.1177/1941738116686545

Chaudhari, A., McKenzie, C. S., Borchers, J. R., & Best, T. M. (2011). Lumbopelvic control and pitching performance of professional baseball pitchers. *The Journal of Strength & Conditioning Research*, *25*(8), 2127–2132.

Chaudhari, A., McKenzie, C. S., Pan, X., & Oñate, J. A. (2014). Lumbopelvic control and days missed because of injury in professional baseball pitchers. *The American Journal of Sports Medicine*, *42*(11), 2734–2740. https://doi.org/10.1177/0363546514545861

Chu, S. K., Jayabalan, P., Kibler, W. B., & Press, J. (2016). The Kinetic Chain Revisited: New concepts on throwing mechanics. *PM&R*, *8*(3), S69–S77. https://doi.org/10.1016/j.pmrj.2015.11.015

Claiborne, T. L., Armstrong, C. W., Gandhi, V., & Pincivero, D. M. (2006). Relationship between hip and knee strength and knee valgus during a single leg squat. *Journal of Applied Biomechanics*, *22*(1), 41–50.

Clauser, C. E., McConville, J. T., & Young, J. W. (1969). *Weight, volume, and center of mass of segments of the human body*. https://doi.org/10.21236/AD0710622

Conte, S., Requa, R. K., & Garrick, J. G. (2001). Disability days in major league baseball. *American Journal of Sports Medicine*, *29*(4), 431–436.

Crossley, K. M., Zhang, W., Schache, A. G., Bryant, A., & Cowan, S. M. (2011). Performance on the single-leg squat task indicates hip abductor muscle function. *The American Journal of Sports Medicine*, *39*(4), 866–873. https://doi.org/10.1177/0363546510395456

Davis, J. T., Limpisvasti, O., Fluhme, D., Mohr, K. J., Yocum, L. A., ElAttrache, N. S., & Jobe, F. W. (2009). The effects of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. *The American Journal of Sports Medicine, 37*(8), 1484–1491. https://doi.org/10.1177/0363546509340226

Dillman, C. J., Fleisig, G. S., & Andrews, J. R. (1993). Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic & Sports Physical Therapy*, *18*(2), 402–408.

DiMattia, M., Livengood, A., Uhl, T., Mattacola, C., & Malone, T. (2005). *What are the validity of the single-leg-squat test and its relationship to hip-abduction strength?* (Vol. 14). https://doi.org/10.1123/jsr.14.2.108

Đorđević, S., Stančin, S., Meglič, A., Milutinović, V., & Tomažič, S. (2011). MC sensor—a aovel method for measurement of muscle tension. *Sensors (Basel, Switzerland)*, *11*(10), 9411. https://doi.org/10.3390/s111009411

Dun, S., Kingsley, D., Fleisig, G. S., Loftice, J., & Andrews, J. R. (2008). Biomechanical comparison of the fastball from wind-up and the fastball from stretch in professional baseball pitchers. *The American Journal of Sports Medicine*, *36*(1), 137–141. https://doi.org/10.1177/0363546507308938

Ellenbecker, T. (2014). *Musculoskeletal examination USA of elite junior tennis players*. ASPETAR.

Elliott, B., Grove, J. R., & Gibson, B. (1988). Timing of the lower limb drive and throwing limb movement in baseball pitching. *International Journal of Sport Biomechanics*, *4*(1), 59–67. https://doi.org/10.1123/ijsb.4.1.59

Erickson, B. J., Zaferiou, A., Chalmers, P. N., Ruby, D., Malloy, P., Luchetti, T. J., … Romeo, A. A. (2017). Are the hamstrings from the drive leg or landing leg more active in baseball pitchers? An electromyographic study. *Journal of Shoulder and Elbow Surgery*, *26*(11), 2010–2016. https://doi.org/10.1016/j.jse.2017.06.041

Escamilla, R. F., Barrentine, S. W., Fleisig, G. S., Zheng, N., Takada, Y., Kingsley, D., & Andrews, J. R. (2007). Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *The American Journal of Sports Medicine*, *35*(1), 23–33. https://doi.org/10.1177/0363546506293025

Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., Zheng, N., & Andrews, J. R. (1998). *Kinematic comparisons of throwing different types of baseball pitches* (Vol. 14). https://doi.org/10.1123/jab.14.1.1

Feltner, M. E., & Dapena, J. (1986). Dynamics of the shoulder and elbow joints of the throwing arm during a baseball pitch. *International Journal of Sports Biomechanics*, *2*, 235–259.

Fleisig, G. S., & Andrews, J. R. (2012a). Prevention of Elbow Injuries in Youth Baseball Pitchers. *Sports Health*, *4*(5), 419–424.

Fleisig, G. S., & Andrews, J. R. (2012b). Prevention of elbow injuries in youth baseball pitchers. *Sports Health: A Multidisciplinary Approach*, *4*(5), 419–424. https://doi.org/10.1177/1941738112454828

Fleisig, G. S., Andrews, J. R., Cutter, G. R., Weber, A., Loftice, J., McMichael, C., … Lyman, S. (2011). Risk of Serious Injury for Young Baseball Pitchers: A 10-year prospective study. *The American Journal of Sports Medicine*, *39*(2), 253–257. https://doi.org/10.1177/0363546510384224

Fleisig, G. S., Andrews, J. R., Dillman, C. J., & Escamilla, R. F. (1995a). *Kinetics of baseball pitching with implications about injury mechanisms* (Vol. 23). https://doi.org/10.1177/036354659502300218

Fleisig, G. S., Andrews, J. R., Dillman, C. J., & Escamilla, R. F. (1995b). Kinetics of baseball pitching with implications about injury mechanisms. *The American Journal of Sports Medicine*, *23*(2), 233–239. https://doi.org/10.1177/036354659502300218

Fleisig, G. S., Barrentine, S. W., Escamilla, R. F., & Andrews, J. R. (1996a). Biomechanics of overhand throwing with implications for injuries. *Sports Medicine*, *21*(6), 421–437. https://doi.org/10.2165/00007256-199621060-00004

Fleisig, G. S., Barrentine, S. W., Escamilla, R. F., & Andrews, J. R. (1996b). Biomechanics of Overhand Throwing with Implications for Injuries: *Sports Medicine*, *21*(6), 421–437. https://doi.org/10.2165/00007256-199621060-00004

Fleisig, G. S., Barrentine, S. W., Zheng, N., Escamilla, R. F., & Andrews, J. R. (1999). Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of Biomechanics*, *32*(12), 1371–1375.

Fleisig, G. S., Escamilla, R. F., Barrentine, S. W., Andrews, J. R., Zarins, B., & Wilk, K. E. (1998). Biomechanics of pitching: Mechanism and motion analysis. In *Injuries in Baseball* (pp. 3–22). Lippincott-Raven.

Fleisig, G. S., Kingsley, D. S., Loftice, J. W., Dinnen, K. P., Ranganathan, R., Dun, S., … Andrews, J. R. (2006). Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *The American Journal of Sports Medicine*, *34*(3), 423–430. https://doi.org/10.1177/0363546505280431

Ford, K. R., Myer, G. D., & Hewett, T. E. (2003). Valgus knee motion during landing in high school female and male basketball players: *Medicine & Science in Sports & Exercise, 35*(10), 1745–1750. https://doi.org/10.1249/01.MSS.0000089346.85744.D9

Garner, J. C., Weimar, W. H., & Madsen, N. (2009). Kinematic And Kinetic Comparison Of Overhand And Underhand Pitching: Implications to proximal-to-distal sequencing. *Medicine & Science in Sports & Exercise, 41*(5), 389. https://doi.org/10.1249/01.MSS.0000355732.11745.52

Gilmer, G. G., Gascon, S. S., & Oliver, G. D. (2018). Classification of lumbopelvic-hip complex instability on kinematics amongst female team handball athletes. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2017.12.009

Gilmer, G. G., Washington, J. K., Dugas, J., Andrews, J. A., & Oliver, G. D. (2017). The role of lumbopelvic-hip complex stability in softball throwing mechanics. *Journal of Sport Rehabilitation*, 1–27. https://doi.org/10.1123/jsr.2017-0276

Gilmer, G., Washington, J., & Oliver, G. D. (2018). Assessment of lumbopelvic–hip complex instability and segmental sequencing amongst softball athletes. *International Biomechanics, 5*, 1–10. https://doi.org/10.1080/23335432.2018.1481456

Guido, J., Werner, S., & Meister, K. (2009). Lower-extremity ground reaction forces in youth windmill softball pitchers. *Journal of Strength & Conditioning Research*, *23*(6), 1873–1876.

Hang, Y.-S., Lippert, F. G., Spolek, G. A., Frankel, V. H., & Harrington, R. M. (1979). Biomechanical study of the pitching elbow. *International Orthopaedics*, *3*(3), 217–223. https://doi.org/10.1007/BF00265715

Henning, L. (2016). *Clinical tests of lumbo-pelvic-hip complex function in Individuals with and without scapular dyskinesis: Implications for identifying individuals at risk for upper extremity injury*. Dissertation, Auburn University.

Higuchi, T., Morohoshi, J., Nagami, T., Nakata, H., & Kanosue, K. (2013). The Effect of fastball backspin rate on baseball hitting accuracy. *Journal of Applied Biomechanics*, *29*(3), 279–284. https://doi.org/10.1123/jab.29.3.279

Hinrichs, R. N. (1990). Adjustments to the segment center of mass proportions of Clauser et al. (1969). *Journal of Biomechanics*, *23*(9), 949–951. https://doi.org/10.1016/0021-9290(90)90361-6

History of Baseball. (n.d.). Retrieved October 24, 2018, from WBSC website: http://www.wbsc.org/baseball/history-of-baseball/

Hore, J., Watts, S., & Tweed, D. (1996). Errors in the control of joint rotations associated with inaccuracies in overarm throws. *Journal of Neurophysiology*, *75*(3), 1013–1025. https://doi.org/10.1152/jn.1996.75.3.1013

How many kids are playing baseball in the world? (2015, March 11). Retrieved October 10, 2018, from Dugout Manager website: https://www.dugoutmanager.com/how-many-kids-are-playing-baseball-in-the-world/

Huang, Y.-H., Wu, T.-Y., Learman, K., & Tsai, Y.-S. (2010). A comparison of throwing kinematics between youth baseball players with and without a history of medial elbow pain. *Journal of Physiology (Chinese)*, *53*(3), 160–166.

Hurwit, D. J., Garcia, G. H., Liu, J., Altchek, D. W., Romeo, A., & Dines, J. (2017). Management of ulnar collateral ligament injury in throwing athletes: A survey of the american shoulder and elbow surgeons. *Journal of Shoulder and Elbow Surgery*, *26*(11), 2023–2028. https://doi.org/10.1016/j.jse.2017.08.005

Ireland, M., Willson, J. D., Ballantyne, B. T., & Davis, I. M. (2003). Hip strength in females with and without patellofemoral pain. *Journal of Orthopaedic & Sports Physical Therapy*, *33*(11), 671–676.

Kageyama, M., Sugiyama, T., Takai, Y., Kanehisa, H., & Maeda, A. (2014). Kinematic and kinetic profiles of trunk and lower limbs during baseball pitching in collegiate pitchers. *Journal of Sports Science & Medicine*, *13*(4), 742.

Kantrowitz, D. E., Trofa, D. P., Woode, D. R., Ahmad, C. S., & Lynch, T. S. (2018). Athletic hip injuries in major league baseball pitchers associated with ulnar collateral ligament tears. *Orthopaedic Journal of Sports Medicine*, *6*(10), 232596711880070. https://doi.org/10.1177/2325967118800704

Keeley, D. W., Hackett, T., Keirns, M., Sabick, M. B., & Torry, M. R. (2008). A biomechanical analysis of youth pitching mechanics: *Journal of Pediatric Orthopaedics*, *28*(4), 452–459. https://doi.org/10.1097/BPO.0b013e31816d7258

Keeley, D. W., Oliver, G. D., & Dougherty, C. (2011). *Shoulder kinetics during pitching and their relation to reported shoulder pain*. 4.

Keeley, D. W., Oliver, G. D., & Dougherty, C. P. (2012a). A biomechanical model correlating shoulder kinetics to pain in young baseball pitchers. *Journal of Human Kinetics*, *34*, 15–20. https://doi.org/10.2478/v10078-012-0059-8

Keeley, D. W., Oliver, G. D., & Dougherty, C. P. (2012b). A biomechanical model correlating shoulder kinetics to pain in young baseball pitchers. *Journal of Human Kinetics*, *34*, 15–20. https://doi.org/10.2478/v10078-012-0059-8

Keeley, D. W., Oliver, G. D., Dougherty, C. P., & Torry, M. R. (2015). Lower body predictors of glenohumeral compressive fforce in high school baseball pitchers. *Journal of Applied Biomechanics*, *31*(3), 181–188. https://doi.org/10.1123/jab.2011-0229

Kerut, E. K., Kerut, D. G., Fleisig, G. S., & Andrews, J. R. (2008). Prevention of arm injury in youth baseball pitchers. *Journal of the Louisiana State Medical Society*, *160*, 4.

Kibler, W. Ben. (1995). Biomechanical analysis of the shoulder during tennis activities. *Clinics in Sports Medicine*, *14*(1), 79–85.

Kibler, W.B. (1998). The role of the scapula in athletic shoulder function. *THE AMERICAN JOURNAL OF SPORTS MEDICINE*, *26*(2), 325–337.

Kibler, W.B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports Medicine*, *36*(3), 189–198.

Kibler, W.B., Wilkes, T., & Sciascia, A. (2013). Mechanics and pathomechanics in the overhead athlete. *Clinics in Sports Medicine*, *32*(4), 637–651. https://doi.org/10.1016/j.csm.2013.07.003

Klingenstein, G. G., Martin, R., Kivlan, B., & Kelly, B. T. (2012). Hip injuries in the overhead athlete. *Clinical Orthopaedics and Related Research®*, *470*(6), 1579–1585. https://doi.org/10.1007/s11999-012-2245-3

Knudson, D. V. (2003). *Fundamentals of biomechanics*. Springer Science & Business Media.

Krajnik, S., Fogarty, K. J., Yard, E. E., & Comstock, R. D. (2010). Shoulder injuries in u.s. High school baseball and softball athletes, 2005-2008. *PEDIATRICS*, *125*(3), 497–501. https://doi.org/10.1542/peds.2009-0961

Krause, D. A., Schlagel, S. J., Stember, B. M., Zoetewey, J. E., & Hollman, J. H. (2007). Influence of lever arm and stabilization on measures of hip abduction and adduction torque obtained by hand-held dynamometry. *Archives of Physical Medicine and Rehabilitation*, *88*(1), 37–42. https://doi.org/10.1016/j.apmr.2006.09.011

Kuhn, J. E., Lindholm, S. R., Huston, L. J., Soslowsky, L. J., & Blasier, R. B. (2003). Failure of the biceps superior labral complex: A cadaveric biomechanical investigation comparing the late cocking and early deceleration positions of throwing. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, *19*(4), 373–379.

Labott, J. R., Aibinder, W. R., Dines, J. S., & Camp, C. L. (2018). Understanding the medial ulnar collateral ligament of the elbow: Review of native ligament anatomy and function. *World Journal of Orthopedics*, *9*(6), 78–84. https://doi.org/10.5312/wjo.v9.i6.78

Laudner, K., Wong, R., Latal, J., & Meister, K. (2018). Descriptive profile of lumbopelvic control in collegiate baseball pitchers. *Journal of Strength and Conditioning Research*, *32*(4), 1150–1154.

Laudner, Kevin G., Moore, S. D., Sipes, R. C., & Meister, K. (2010). Functional Hip Characteristics of Baseball Pitchers and Position Players. *The American Journal of Sports Medicine*, *38*(2), 383–387. https://doi.org/10.1177/0363546509347365

Laudner, K.G., Wong, R., & Meister, K. (2018). The influence of lumbopelvic control on shoulder and elbow kinetics in elite baseball pitchers. *Journal of Shoulder and Elbow Surgery*. https://doi.org/10.1016/j.jse.2018.07.015

Lewis, C., Foch, E., Luko, M., Loverro, K., & Khuu, A. (2015). Differences in lower extremity and trunk kinematics between single leg squat and step down tasks. *PLoS One*, *10*(5), 1–15.

Lin, D. J., Wong, T. T., & Kazam, J. K. (2018). Shoulder Injuries in the Overhead-Throwing Athlete: Epidemiology, mechanisms of injury, and imaging findings. *Radiology*, *286*(2), 370–387. https://doi.org/10.1148/radiol.2017170481

Linter, D., Noonan, T. J., & Kibler, W. B. (2008). Injury patterns and biomechanics of the athlete's shoulder. *Clin Sports Med*, *27*(4), 527–551.

Litner, D. (2008). Injury patterns and biomechanics of athlete's shoulder. *Clinics in Sports Medicine*, *27*(4), 527–551.

Logar, G., & Munih, M. (2015). Estimation of joint forces and moments for the in-run and take-off in ski jumping based measrements with wearable inertial sensors. *Sensors*, *15*(5), 11258–11276. https://doi.org/10.3390/s150511258

Lyman, S., & Fleisig, G. S. (2005). Baseball injuries. *Medicine & Science in Sports & Exercise*, *49*, 9–30.

Lyman, S., Fleisig, G. S., & Andrews, J. A. (2002). Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *American Journal of Sports Medicine*, *30*(4), 463–468.

Matsuo, T., Fleisig, G. S., Zheng, N., & Andrews, J. R. (2006). Influence of shoulder abduction and lateral trunk tilt on peak elbow varus torque for college baseball pitchers durinf simulated pitching. *Journal of Applied Biomech*, *22*, 93–102.

McFarland, E. G., & Wasik, M. (1998). Epidemiology of collegiate baseball injuries. *Clinical Journal Sports Medicine*, *8*(1), 10–30.

McMullen, J., & Uhl, T. L. (2000). A kinetic chain approach for shoulder rehabilitation. *Journal of Athletic Training*, *35*(2), 329–337.

Mehta, R. D., & Pallis, J. D. (n.d.). Sports ball aerodynamics: Effects of velocity, spin and surface roughness. In *MATERIALS AND SCIENCE IN SPORTS* (pp. 185–197). Warrendale, PA.

Melugin, H. P., Leafblad, N. D., Camp, C. L., & Conte, S. (2018). Injury Prevention in Baseball: From youth to the pros. *Current Reviews in Musculoskeletal Medicine*, *11*(1), 26–34. https://doi.org/10.1007/s12178-018-9456-5

Mullaney, M., McHugh, M., M Donofrio, T., & Nicholas, S. (2005). *Upper and lower extremity muscle fatigue after a baseball pitching performance* (Vol. 33). https://doi.org/10.1177/0363546504266071

Nagami, T., Higuchi, T., & Kanosue, K. (2013). How baseball spin influences the performance of a pitcher. *J Phys Fitness Sports Med*, *2*(1), 63–68.

Nathan, A. M. (2008). The effect of spin on the flight of a baseball. *American Journal of Physics*, *76*(2), 119–124. https://doi.org/10.1119/1.2805242

Nishiwaki, G. A., Urabe, Y., & Tanaka, K. (2006). EMG analysis of lower extremity muscles in three different squat exercises. *Journal of the Japanese Physical Therapy Association*, *9*(1), 21–26. Retrieved from https://www.jstage.jst.go.jp/article/jjpta/9/1/9_1_21/_article/-char/ja/

Nordin, M., & Frankel, V. H. (2001). *Basic biomechanics of the musculoskeletal system*. Lippincott Williams & Wilkins.

Oliver, G. D. (2014). Relationship between gluteal muscle activation and upper extremity kinematics and kinetics in softball position players. *Med Biol Eng Comput*, *52*, 265–270.

Oliver, G. D., & Keeley, D. W. (2010a). Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high-school baseball pitchers. *Journal of Strength and*

Conditioning Research, *24*(11), 3015–3022. https://doi.org/10.1519/JSC.0b013e3181c865ce

Oliver, G. D., & Keeley, D. W. (2010b). Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball pitchers. *Journal of Strength and Conditioning Research*, *24*(12), 3241–3246. https://doi.org/10.1519/JSC.0b013e3181cc22de

Oliver, G. D., Lohse, K., & Gascon, S. (2015). Kinematics and kinetics of youth baseball catchers and pitchers. *Sports*, *3*(3), 246–257. https://doi.org/10.3390/sports3030246

Oliver, G. D., & Plummer, H. A. (2011). Ground reaction forces, kinematics, and muscle activations during the windmill softball pitch. *Journal of Sport Science*, *29*(10), 1071–1077.

Oliver, G. D., & Weimar, W. H. (2015). Hip range of motion and scapula position in youth baseball pitching pre and post simulated game. *Journal of Sports Sciences*, *33*(14), 1447–1453. https://doi.org/10.1080/02640414.2014.990493

Oliver, G. D., Weimar, W. H., & Henning, L. (2016). Effects of a simulated game on muscle activation in youth baseball pitchers. *Journal of Strength & Conditioning Research*, *30*(2), 415–420.

Oliver, G. D., Weimar, W. H., & Plummer, H. A. (2015). Gluteus medius and scapula muscle activations in youth baseball pitchers. *Journal of Strength & Conditioning Research*, *6*(29), 1494–1499.

Olsen, S. J., Fleisig, G. S., Dun, S., Loftice, J., & Andrews, J. R. (2006). Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *The American Journal of Sports Medicine*, *34*(6), 905–912. https://doi.org/10.1177/0363546505284188

Oyama, S., Yu, B., Blackburn, T., Padua, D., Li, L., & Myers, J. B. (2013). Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. *American Journal of Sports Medicine, 41*(10), 2430–2438. https://doi.org/10.1177/0363546513496547

Pasternack, J. S., Veenema, K. R., & Callahan, C. M. (1996). Baseball injuries: A little league survey. *Pediatrics*, *98*(3), 445–448.

Petty, D. H., Andrews, J. R., Fleisig, G. S., & Cain, E. L. (2004). Ulnar Collateral Ligament Reconstruction in High School Baseball Players: Clinical results and injury Rrisk factors. *The American Journal of Sports Medicine*, *32*(5), 1158–1164. https://doi.org/10.1177/0363546503262166

Pitch Smart. (n.d.). Retrieved July 24, 2018, from Major League Baseball website: http://m.mlb.com/pitchsmart/pitching-guidelines/

Plummer, H. A., & Oliver, G. D. (2014). The relationship between gluteal muscle activation and throwing kinematics in baseball and softball catchers. *Journal of Strength & Conditioning Research*, *28*(1), 87–96.

Plummer, H. A., & Oliver, G. D. (2015). Quantitative analysis of the kinematics of the overhead lacrosse shot in youth. *International Biomechanics*, *2*(1), 29–35. https://doi.org/10.1080/23335432.2015.1017608

Plummer, H. A., Oliver, G. D., Powers, C., & Michener, L. (2018). Trunk lean during a single-leg squat is associated with trunk lean during pitching. *International Journal of Sports Physical Therapy*, *13*(1), 58–65.

Probability. (2018, November 12). Retrieved October 10, 2018, from Probability website: http://www.hsbaseballweb.com/probability.htm

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. *The Journal of Biomechanics*, *26*(1), 125–135.

Reeves, B. (1968). Experiments on the tensile strength of the anterior capsular structures of the shoulder in man. *J Bone Joint Surg Br, 50*, 858–865.

Robb, A. J., Fleisig, G. S., Wilk, K. E., Marcrina, L., Bolt, B., & Pajaczkowski, J. (2010). Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *American Journal of Sports Medicine*, *38*(12), 2487–2493.

Sabick, M. B., Kim, Y. K., Torry, M. R., Keirns, M. A., & Hawkins, R. J. (2005). Biomechanics of the Shoulder in Youth Baseball Pitchers: Implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *The American Journal of Sports Medicine*, *33*(11), 1716–1722. https://doi.org/10.1177/0363546505275347

Sabick, M. B., Torry, M. R., Lawton, R. L., & Hawkins, R. J. (2004). Valgus torque in youth baseball pitchers: A biomechanical study. *Journal of Shoulder and Elbow Surgery*, *13*(3), 349–355. https://doi.org/10.1016/j.jse.2004.01.013

Saeterbakken, A. H., van den Tillaar, R., & Seiler, S. (2011). Effects of core stability training on throwing velocity in female handball players. *Journal of Strength & Conditioning Research*, *25*(3), 712–718.

Sauers, E. L., Huxel Bliven, K. C., Johnson, M. P., Falsone, S., & Walters, S. (2014). Hip and glenohumeral rotation range of motion in healthy professional baseball pitchers and position players. *The American Journal of Sports Medicine*, *42*(2), 430–436. https://doi.org/10.1177/0363546513508537

Scher, S., Anderson, K., Weber, N., Bajorek, J., Rand, K., & Bey, M. J. (2010). Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. *Journal of Athletic Training*, *45*(2), 191–197. https://doi.org/10.4085/1062-6050-45.2.191

Sciascia, A., Thigpen, C., Namdari, S., & Baldwin, K. (2012). Kinetic chain abnormalities in the athletic shoulder. *Sports Med Arthrosc Rev*, *20*(1), 16–21.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P., & Romeo, A. A. (2010). The Kinetic Chain in Overhand Pitching: Its potential role for performance enhancement and injury prevention. *Sports Health: A Multidisciplinary Approach*, *2*(2), 135–146. https://doi.org/10.1177/1941738110362656

Sigward, S. M., Ota, S., & Powers, C. M. (2008). Predictors of frontal plane knee excursion during a drop land in young female soccer players. *Journal of Orthopaedic & Sports Physical Therapy*, *38*(11), 661–667. https://doi.org/10.2519/jospt.2008.2695

Solomito, M. J., Garibay, E. J., & Nissen, C. W. (2018). Sagittal plane trunk tilt is associated with upper extemity joint moments and ball velocity in collegiate baseball pitchers. *Orthopaedic Journal of Sports Medicine*, *6*(10), 2325967118800240. https://doi.org/10.1177/2325967118800240

Spin Rate Part II: Spin Axis & Useful Spin. (2016, November 28). Retrieved August 30, 2018, from Driveline Baseball website: https://www.drivelinebaseball.com/2016/11/spin-rate-part-ii-spin-axis-useful-spin/

Spin Rate: What we know now. (2016, November 17). Retrieved November 1, 2018, from Driveline Baseball website: https://www.drivelinebaseball.com/2016/11/spin-rate-what-we-know-now/

Stodden, D. F., Fleisig, G. S., McLean, S. P., Lyman, S. L., & Andrews, J. R. (2001). Relationship of pelvis and upper torso kinematics to pitched baseball velocity. *Journal of Applied Biomechanics*, *17*(2), 164–172.

Stodden, D. F., Langendorfer, S. J., Fleisig, G. S., & Andrews, J. R. (2006). Kinematic Constraints Associated With the Acquisition of Overarm Throwing Part II: Upper extremity actions. *Research Quarterly for Exercise and Sport*, *77*(4), 428–436. https://doi.org/10.5641/027013606X13080770015166

Stodden, D., Fleisig, G., Mclean, S., & Andrews, J. (2005). *Relationship of Biomechanical Factors to Baseball Pitching Velocity: Within Pitcher Variation* (Vol. 21). https://doi.org/10.1123/jab.21.1.44

Vlietstra, N. (n.d.). *Comparing Methods for Full Body Inverse Dynamics Analysis of a Standing Long Jump*. 56.

Weber, A. E., Kontaxis, A., O'Brien, S. J., & Bedi, A. (2014). The biomechanics of throwing: Simplified and cogent. *Sports Med Arthrosc Rev*, *22*, 72–79.

Werner, S. L., Gill, T. J., Murray, T. A., Cook, T. D., & Hawkins, R. J. (2001). Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers. *The American Journal of Sports Medicine*, *29*(3), 354–358. https://doi.org/10.1177/03635465010290031701

Wilk, K. E., Meister, K., & Andrews, J. A. (2002). Current concepts in the rehabilitation of the overhead throwing athlete. *The American Journal of Sports Medicine*, *30*(1), 136–151.

Wilk, K. E., Meister, K., Fleisig, G. S., & Andrews, J. R. (2000). Biomechanics of the overhead throwing motion. *Sports Medicine and Arthroscopy Review*, *8*(2), 124–134.

Willson, J. D., Ireland, M. L., & Davis, I. (2006). Core strength and lower extremity alignment during single leg squats: *Medicine & Science in Sports & Exercise*, *38*(5), 945–952. https://doi.org/10.1249/01.mss.0000218140.05074.fa

Woods, G., Spaniol, F., & Bonnette, R. (2008). The relationship between finger strength and spin rate of curve balls thrown by NCAA Division I baseball pitchers. Retrieved October 4, 2018, from https://sportdocbox.com/Baseball/68661103-The-relationship-between-finger-strength-and-spin-rate-of-curve-balls-thrown-by-ncaa-division-i-baseball-pitchers.html

Worrell, T. W., & Perrin, D. H. (1992). Hamstring muscle injury: The influence of strength, flexibility, warm-up, and fatigue. *Journal of Orthopaedic & Sports Physical Therapy*, *16*(1), 12–18. Retrieved from http://www.jospt.org/doi/abs/10.2519/jospt.1992.16.1.12

Wu, G., Siegler, S., Allard, P., Kirtley, K., Leardini, A., Rosenbaum, D., … Witte, H. (2002). ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: Ankle, hip, and spine. *Journal of Biomechanics*, *35*(4), 543–548.

Wu, G., van der Helm, F. C. T., (DirkJan) Veeger, H. E. J., Makhsous, M., Van Roy, P., Anglin, C., … Buchholz, B. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: Shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*(5), 981–992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Yamanouchi, T. (1998). EMG analysis of the lower extremities during pitching in high-school baseball. *The Kurume Medical Journal*, *45*(1), 21–25. Retrieved from https://www.jstage.jst.go.jp/article/kurumemedj1954/45/1/45_1_21/_article/-char/ja/

Zeller, B. L., McCrory, J. L., Kibler, W. B., & Uhl, T. L. (2003). Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *The American Journal of Sports Medicine*, *31*(3), 449–456.

Appendix A

HEALTH and SPORT HISTORY QUESTIONNAIRE

PARTICIPANT INFORMATION

First Name: Middle Name:
Last Name:
DOB (mm/dd/yyyy): Age:
Email:
Phone number:
Street Address:
City: State: Zip Code:

SPORT HISTORY

1. Is baseball/softball your primary sport? **YES NO**
2. What is your dominate side? **Right Left Both/Either**
3. What arm do you use to throw? **Right Left**
4. What side do you hit? **Right Left Both**
5. Are you allergic to adhesive tape? **YES NO**

Sports Information

6. At what level do you play baseball/softball? (select all that apply)
   Professional NCAA Div I NCAA Div II NCAA Div III
   High School Middle School/Junior High Youth (Dixie, Little League, etc)
   Regional Level Travel Travel (Select) National Level Travel
   National Team Other ___________________________
7. Do you play other sports? **YES NO**
8. List all the sports you play

Name of sport	Level at which you play	Months per year you play

9. At what age did you start playing sports? _____
10. At what age did you start playing baseball/softball? _____
11. How many years have you been playing competitive baseball/softball? _____
12. Do you consider baseball/softball more important than your other sports? **YES NO**
13. Have you quit another sport to focus on your primary sport? **YES NO**
14. Do you consider your primary sport more important than your other sport? **YES NO**
15. What position is your primary position?
    Pitcher Catcher Middle Infielder Corner Infielder Outfielder
    Designated Hitter
16. What position do you play when you are not playing your primary position? (select all that apply)
    Pitcher Catcher Middle Infielder Corner Infielder Outfielder
    Designated Hitter I only play my primary position

17. How many months of the year are you…

IN season for baseball/softball ________
IN season for other sports ________
OFF season for ALL sports ________
Training for baseball/softball ________

18. How many baseball/softball teams have you played on in the past year? _______

19. Based on your baseball/softball season please state how many hours a week you devote to:

OFF season for baseball/softball practice ________
OFF season strength and conditioning ________
OFF season practice for sports other than baseball/softball ________
IN season baseball/softball practice ________
IN season strength and conditioning ________
IN season practice for sports other than baseball/softball ________

20. How often….??

A. Do you feel tired of baseball/softball

NEVER **RARELY** **SOMETIMES** **OFTEN** **ALWAYS**

B. Do you want to take a break or quit baseball/softball

NEVER **RARELY** **SOMETIMES** **OFTEN** **ALWAYS**

C. Do you wish you could play more or different sports, other than baseball/softball

NEVER **RARELY** **SOMETIMES** **OFTEN** **ALWAYS**

D. Has your baseball/softball coach told you not to play other sports?

NEVER **RARELY** **SOMETIMES** **OFTEN** **ALWAYS**

E. Have your parents said they want you to play baseball/softball over other sports

NEVER **RARELY** **SOMETIMES** **OFTEN** **ALWAYS**

21. Estimate the total number of throws/pitches thrown during….

A. Warm-up prior to an IN season practice

0 20 40 60 80 100 120 140 160 180 200

B. An IN season practice

0 20 40 60 80 100 120 140 160 180 200

C. Cool-down after an IN season practice

0 20 40 60 80 100 120 140 160 180 200

D. Warm-up prior to an IN season game

0 20 40 60 80 100 120 140 160 180 200

E. An IN season game

0 20 40 60 80 100 120 140 160 180 200

F. Cool-down after to an IN season game

0 20 40 60 80 100 120 140 160 180 200

HEALTH HISTORY:

22. Have you ever had surgery? **YES** **NO**

23. Have you ever had a serious injury? (requiring one month or more of rest from competitive activity) **YES** **NO**

If **YES** to #23 proceed to #24
If **NO** to #23 proceed to #30

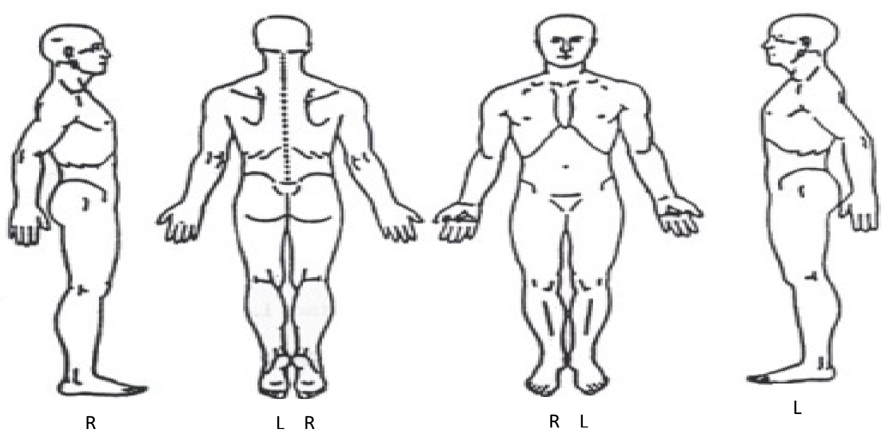
24. Please describe your injury
25. How long ago was your most recent serious injury? ______yr ________mo
26. Was your injury related to sport participation? **YES** **NO**
27. Was your injury related to baseball/softball participation? **YES** **NO**
28. What type of treatment did you receive? (check all that apply)

Immobilization **Pain Medication** **Other Medication** **Surgery**
Physical Therapy **Other**

29. How much, if any, playing/practice time was missed?
30. Do you currently experience any pain/discomfort? **YES** **NO**

If **YES** to #30 proceed to #31
If **NO** to #30 proceed to #43

31. Please click on the area of the body you are experiencing pain/discomfort



32. When do you experience pain?(circle all that apply)

After throwing **Lifting heavy objects** **overhead movement**
after athletic movement **sitting** **all the time** **during throwing**
standing **randomly** **while walking**

33. Please rate the level of your pain. 0=least pain 10=most pain

0 1 2 3 4 5 6 7 8 9 10

34. How long have you been experiencing pain? __days __weeks __mo

35. Is this a reoccurring or new issue? **Reoccurring** **New**

36. What type of pain/discomfort are you experiencing? (check all that apply)

Aching **agonizing** **pressure** **cramping** **dull**
squeezing **pounding** **nagging** **radiating**

sharp pain **penetrating** **tingling** **throbbing**
shooting **tender** **stabbing** **gnawing** **other**

37. Is your pain/discomfort related to sport participation? **YES** **NO**

38. Is your pain/discomfort related to baseball/softball participation? **YES** **NO**

39. How would you describe the onset of your pain/discomfort? **Gradual** **Sudden**

40. Have you sought medical consultation because of your pain (including team athletic trainer, physical therapist, or doctor)? **YES** **NO**

41. Have you received treatment for your pain? **YES** **NO**

42. If you are currently experiencing pain/discomfort, please answer the following questions..
A. My pain has caused a decrease in my playing time
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

B. My pain has made it difficult to perform tasks
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

C. My pain has limited my ability to perform other activities
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

D. I have had to modify my behavior to avoid further pain
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

E. My throwing accuracy has decreased since my pain
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

F. My pain has inhibited my ability to perform high effort throws
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

G. I have modified my throwing/pitching motion to avoid further pain
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

H. My recovery time has increased since my pain

Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

I. My performance has suffered due to my pain
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

J. I have lost range of motion because of my pain
Strongly agree **Agree** **Neither agree or disagree** **Disagree**
strongly disagree

K. My energy level has decreased due to my pain
Strongly agree **Agree** **Neither agree or disagree** **disagree**
strongly disagree

43. Please rate your satisfaction with your….? 0=Not satisfied; 10=Highly satisfied
A. Current physical health
0 1 2 3 4 5 6 7 8 9 10
B. Athletic Performance
0 1 2 3 4 5 6 7 8 9 10
C. Enjoyment in your baseball/softball participation
0 1 2 3 4 5 6 7 8 9 10

Appendix B

The Auburn University Institutional Review Board has approved this Document for use from 03/21/2018 to 03/20/2019
Protocol # 18-12 EP 1803

Participant Informed Consent

SCHOOL O F
KINESIOLOGY
301 Wire Road
Auburn , AL 36849
(334) 884-4483

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

Auburn University
CONSENT TO PARTICIPATE IN RESEARCH
Lower Extremity Influence on Baseball and Softball Pitching

Explanation and Purpose of the Research

You are being asked to participate in a research study for the Sports Medicine & Movement Lab in the School of Kinesiology. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to confidentially and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the influence of the lower extremity on baseball and softball pitching mechanics among pitchers of various ages (9-25) without surgery for the past 6 months. To investigate this, bilateral hip and shoulder range of motion will be measured as well as pitching mechanics and muscle activations. You will be equipped with eleven electromagnetic sensors, approximately the size of a pencil eraser to obtain pitching mechanics and eight sensors the size of a quarter to obtain muscle activation information. Following sensor attachment, you will throw three of each pitch type that you typically throw.

Research Procedures

To be considered for this study, you must be pain, injury and surgery free for at least the past 6 months. In addition, you must be currently playing at a competitive level. You must also not have an allergy to adhesive tape.

Testing for this research will require you to be dressed in shorts, t-shirt, and tennis shoes. Your height, body mass, and age will be documented. Height and mass will be measured with a common Standiometer (scale with height ruler) and will be recorded to the nearest tenth of a kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month. Range of motion will be measured with a goniometer and will be recorded to the nearest degree.

Once these measurements have been collected, your throwing side biceps tendon will be imaged via US. This will consist of you sitting with your arm at your side and elbow flexed. Once the US has recorded an image of the biceps tendon, eleven electromagnetic sensors, approximately the size of a pencil eraser, will be attached to the skin with double-sided tape and cover roll. The sensors will be placed on the dominant throwing arm at the following locations: acromioclavicular joint [tip of shoulder], deltoid tuberosity of the humerus (superior lateral aspect of upper arm), and the distal radialulnar joint (superior aspect of the wrist). The remaining sensors will be placed on the C7 spinal vertebrae, on the sacrum (low back), on the middle of Participant Initials: _____

the lateral aspect of each thigh, on the middle of the lateral aspect of each lower leg, and on the top of each shoe (superior to the tip of the second toe). Eight electromyographic electrodes will be placed on the following muscles bilaterally: gluteus maximus, medial hamstring, lateral hamstring, femoral adductors. Isokinetic muscle testing will be performed to establish baseline muscle activity in which all data will be compared.

Following sensor placement, you will be allotted an unlimited time to warm-up. You will be asked to throw three maximal effort pitches of each of your commonly throwing pitches. (Baseball pitchers will throw maximum of these pitches: fastball, curve ball, change up, slider, screw) (Softball pitchers will throw maximum of these pitches: fastball, change up, curve ball, rise ball, drop ball). Testing will take approximately 1 hour and 15 minutes to complete.

Potential Risks
As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in competitive baseball or softball and may include: death, muscle strain, muscle soreness, ligament and tendon damage, and general overuse injury to the throwing athlete. Every effort will be made to minimize these risks and discomforts. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue or feel symptoms of any other possible complications that might occur during testing.

To reduce the risk of injury, certain precautions will be taken. During data collection, two board certified athletic trainers will be present to monitor you as you hit. Ample warm-up and cool- down periods will be required of you, water will be provided to you as needed, and ice will be made available after testing.

The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you should let the researcher know and she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. In the unlikely event that you sustain an injury from participation in this study, the investigators have no current plans to provide funds for any medical expenses or other costs you may incur.

Confidentiality
All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use and will not be disclosed to any person(s) outside of the research team. The results of this study may be published as scientific research. Your name or identity shall not be revealed should such publication occur.

Participation and Benefits
Participation in this research is strictly voluntary and refusal to participate will result in no penalty. If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the School of Kinesiology.

By participating in this study, you will receive information regarding core stability and throwing mechanics that may help prevent injury. This will allow you the opportunity to alter your training programs in an effort to minimize injury resulting from fatigue, etc.

Participant Initials ____________

Questions Regarding the Study

If you have questions about this study, please ask them now. If you have questions later you may contact Dr. Gretchen Oliver, 844-1497 or goliver@auburn.edu.

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____ __________________

Printed Name of Participant Date of Birth

____ __________________

Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____ __________________

Signature of Investigator Date

The Auburn University Institutional Review Board has approved this Document for use from
03/21/2018 to 03/20/2019
Protocol # 18-12 EP 1803

Appendix C

Informed Consent

The Auburn University Institutional Review Board has approved this Document for use from 03/21/2018 to 03/20/2019
Protocol # 18-12 EP 1803

SCHOOL O F
KINESIOLOGY
301 Wire Road
Auburn , AL 36849
(334) 884-4483

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

Parental Permission/Minor Assent

Lower Extremity Influence on Baseball and Softball Pitching
CONSENT TO PARTICIPATE IN RESEARCH

Explanation and Purpose of the Research
We need your permission, as your child is under the age of 19, for your child's participation in a research study for the Sports Medicine & Movement Group in the School of Kinesiology by Dr. Gretchen Oliver. Before agreeing to participate in this study, it is vital that you and your child understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to confidentiality and your child's right to discontinue their participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the influence of the lower extremity on baseball and softball pitching mechanics among pitchers of various ages (9-25) without surgery for the past 6 months. To investigate this, bilateral hip and shoulder range of motion will be measured as well as pitching mechanics and muscle activations. Your child will be equipped with eleven electromagnetic sensors, approximately the size of a pencil eraser to obtain pitching mechanics and eight sensors the size of a quarter to obtain muscle activation information. Following sensor attachment, your child will throw three of each pitch type that they typically throw.

Research Procedures
To be considered for this study, your child must you must be pain, injury and surgery free for at least the past 6 months. In addition, must be currently playing at a competitive level. Your child must also not have an allergy to adhesive tape.

Testing for this research will require your child to be dressed in shorts, t-shirt, and tennis shoes. Height, body mass, and age will be documented. Height and mass will be measured with a common Standiometer (scale with height ruler) and will be recorded to the nearest tenth of a kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month. Range of motion will be measured with a goniometer and will be recorded to the nearest degree.

Once these measurements have been collected, eleven electromagnetic sensors, approximately the size of a pencil eraser, will be attached to the skin with double-sided tape and cover roll. The sensors will be placed on the dominant throwing arm at the following locations: acromioclavicular joint (tip of shoulder), deltoid tuberosity of the humerus (superior lateral aspect of upper arm), and the distal radialulnar joint (superior aspect of the wrist). The remaining sensors will be placed on the C7 spinal vertebrae, on the sacrum (low back), on the

Participant Initials________________________

Parent Initials ________________________

The Auburn University Institutional Review Board has approved this Document for use from
03/21/2018 to 03/20/2019
Protocol # 18-12 EP 1803

middle of the lateral aspect of each thigh, on the middle of the lateral aspect of each lower leg, and on the top of each shoe (superior to the tip of the second toe). Eight electromyographic electrodes will be placed on the following muscles bilaterally gluteus maximus, medial hamstring, lateral hamstring, femoral adductors. Isokinetic muscle testing will be performed to establish baseline muscle activity in which all data will be compared.

Following sensor placement, your child will be allotted an unlimited time to warm-up. Your child will be asked to throw three maximal effort pitches of each of their commonly throwing pitches. (Baseball pitchers will throw maximum of these pitches: fastball, curve ball, change up, slider, screw) (Softball pitchers will throw maximum of these pitches: fastball, change up, curve ball, rise ball, drop ball). Testing will take approximately 1 hour and 15 minutes to complete.

Potential Risks

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in competitive baseball and softball and may include: death, muscle strain, muscle soreness, ligament and tendon damage, and general overuse injury to the throwing athlete. Every effort will be made to minimize these risks and discomforts. It is your child's responsibility, as a participant, to inform the investigators if they notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing.

To reduce the risk of injury, certain precautions will be taken. During data collection, two board certified athletic trainers will be present to monitor you as you hit. Ample warm-up and cool- down periods will be required of your child, water will be provided as needed, and ice will be made available after testing.

The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you or your child should let the researcher know and she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. In the unlikely event that you sustain an injury from participation in this study, the investigators have no current plans to provide funds for any medical expenses or other costs you may incur.

Confidentiality

All information gathered in completing this study will remain confidential. Your child's individual performance will not be made available for public use and will not be disclosed to any person(s) outside of the research team. The results of this study may be published as scientific research. Your child's name or identity shall not be revealed should such publication occur.

Participation and Benefits

Participation in this research is strictly voluntary and refusal to participate will result in no penalty. If you or your child change your minds about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your child's data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your child's future relations with Auburn University or the School of Kinesiology.

By participating in this study, your child will receive information regarding core stability and throwing mechanics that may help prevent injury. This will allow your child the opportunity to alter training programs in an effort to minimize injury resulting from fatigue, etc

Participant Initials ____

Parent Initials _______

The Auburn University Institutional Review Board has approved this Document for use from 03/21/2018 to 03/20/2019 Protocol # 18-12 EP 1803

Questions Regarding the Study

If you have questions about this study, please ask them now. If you have questions later you may contact Dr. Gretchen Oliver, 844-1497 or goliver@auburn.edu.

If you have any questions about your child's rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH FOR YOUR CHILD TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO ALLOW YOUR CHILD'S PARTICIPATION.

______________________________	______yr. ______mo.
Printed Name of Parent	Age of Participant
______________________________	______________
Signature of Parent	Date
______________________________	
Printed Name of Participant	
______________________________	______________
Signature of Participant	Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____ ___________________

Signature of Investigator, Dr. Gretchen Oliver Date

The Auburn University Institutional Review Board has approved this Document for use from 03/21/2018 to 03/20/2019 Protocol # 18-12 EP 1803

3 of 3

APPENDIX D

Inverse dynamics equations
Top-down approach

The Newton-Euler equations of motion solution starts at the hand(s) and solve each segment down, all the way to the ground, if desired. This “top-down” solution assumes the reaction force and torque at the hand are zero. Air resistance is neglected for all the segments for all solution methods (Vlietstra, n.d.).

The model is defined as rigid bodies with constant weights. The movement of the system is described by the Newton–Euler inverse dynamics analysis. The sum of the forces acting on each segment is shown in equation (1)

$$\Sigma F_x = m_{seg} a_{CoM} \tag{1}$$

Joint forces will be calculated for shoulder and elbow. Link-segment model for the upper arm of the baseball pitcher requires the parameters of each segment, such as mass (m_{seg}) and acceleration (a_{CoM}) of the segments center of mass. In this study, these data will obtained from statistical tables and calculated based on the height and weight of the participant(s) (Clauser et al., 1969; Hinrichs, 1990). Beginning at the proximal segment, where the external forces are not known, the procedure continues to the shoulder segment (F_{hand}, F_{elbow}, F_{shld}) solving the equations in the order demonstrated below:

$$F_{hand} = m_{hand} * a_{hand} \tag{2}$$
$$F_{hand} - f_{forearm} = m_{forearm} * a_{forearm} \tag{3}$$
$$F_{forearm} - f_{shld} = m_{ua} * a_{ua} \tag{4}$$

1. In Equation (2), F_{hand} is calculated; m_{hand} is constant; a_{hand} is acquired with the The MotionMonitor® (Innovative Sports Training, Chicago, IL., USA). F_{hand} is calculated in the segment local coordinate system; for use in the next step, it should be transformed to the global coordinate system.
2. In Equation (3), F_{elbow} is calculated; f_{hand} is transformed from the global to forearm local coordinate system; $m_{forearm}$ is constant; $a_{forearm}$ COM is acquired with The MotionMonitor®. F_{elbow} is calculated in the segment local coordinate system; for use in the next step, it should be transformed to the global coordinate system.
3. In Equation (4), F_{shld} is calculated; f_{shld} is transformed from the global to upper arm (ua) local coordinate system; m_{UA} is constant; a_{ua} COM is acquired with The MotionMonitor®. F_{shld} is calculated in the segment local coordinate system; for use in the next step, it should be transformed to the global coordinate system (Logar & Munih, 2015).

APPENDIX E

Participant Data Form

Name/moniker			
MM User ID:			
Rapsodo User ID:			

RMS Values		Trial 1	Trial 2	Trial 3	Trial 4
	L Shld				
	R Shld				
	L Hip				
	R Hip				

Single leg squats (hands on hips)	3 on both sides	

Warm-up time	

#	Glove condition	Foot position (out/neu/in)	Rapsodo #	Speed	#	Glove condition	Foot position (out/neu/in)	Rapsodo #	Speed
1					**16**				
2					**17**				
3					**18**				
4					**19**				
5					**20**				
6					**21**				
7					**22**				
8					**23**				
9					**24**				
10					**25**				
11					**26**				
12					**27**				
13					**28**				
14					**29**				
15					**30**				

Single leg squats (arms crossed)	3 on both sides	

APPENDIX F

Single leg squat (SLS) Performance Normality

Stance leg (right)

Average degree of knee valgus (-15.7° ± 11.3°, N = 25) was normally distributed with a Skewness of α_3 = -.313 (*SEskew = .481* = .456) and Kurtosis of α_4 = -.111 (*SEkurt = .935* .887) (Figure F1, Table F1).

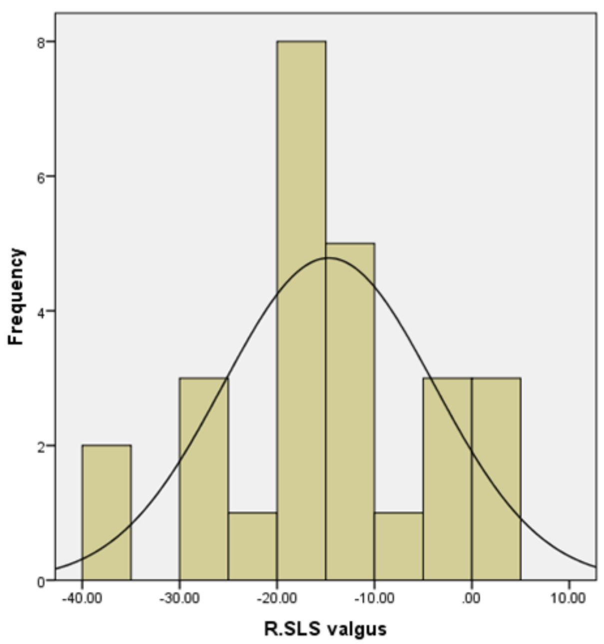


Figure F1: Distribution of stance leg (right) knee valgus, N=25

Table F1: Tests for normality of stance leg (right) knee valgus, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
R.SLS valgus	.112	26	.200*	.953	26	.273

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Lead leg (Left)

Average degree of knee valgus (-11.1° ± 4.9°, *N* = 26) was normally distributed with a Skewness of α_3 = -.339 (*SEskew = .481* .456) and Kurtosis of α_4 = .272 (*SEkurt = .935* .887) (Figure F2, Table F2).

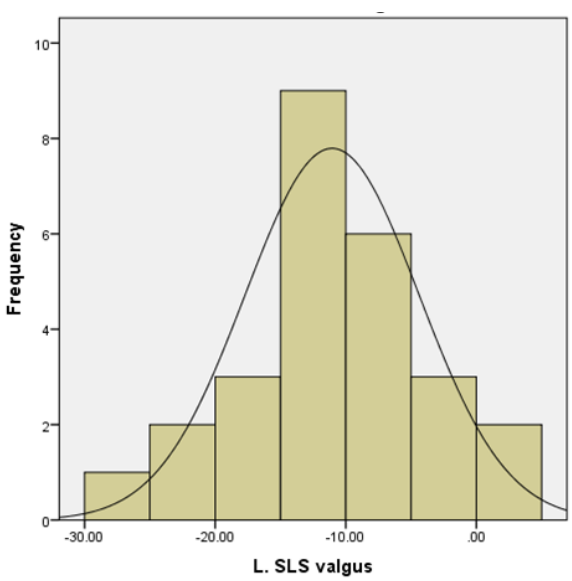


Figure F2: Distribution of lead leg (left) knee valgus, N=26

Table F2: Tests for normality of lead leg (left) knee valgus, N=26

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
L. SLS valgus	.106	26	.200*	.971	26	.640

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Research Question 1 Normality

Anterior/posterior (X) shoulder forces at MER (31.2 N ± 162.4, *N* = 25), expressed as a percent of height and weight, with a Skewness of α_3 = .123 (*SEskew = .481* .481) and Kurtosis of α_4 = -.129 (*SEkurt = .935* = .935) (Figure F3, Table F3).

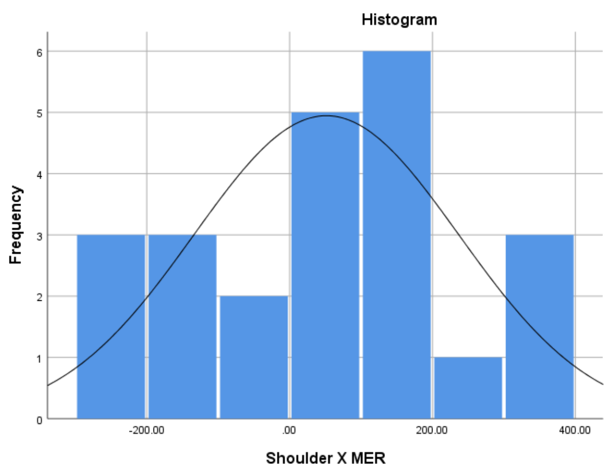


Figure F3: Normal distribution of anterior/posterior (X) shoulder forces at MER, N=25

Table F3: Tests for normality of anterior/posterior (X) shoulder forces at MER, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Shoulder X MER	.100	23	.200*	.964	23	.542

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Anterior/posterior (X) shoulder forces at BR (-155.0 N ± 403.1, N = 25), expressed as a percent of height and weight, with a Skewness of α_3 = 1.82 (*SEskew* = .481) and Kurtosis of α_4 = 7.29 (*SEkurt = .935*) (Figure F4, Table F4).

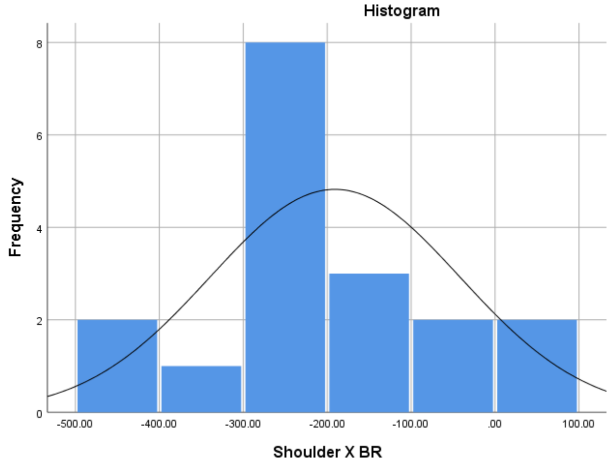


Figure F4: Normal distribution of anterior/posterior (X) shoulder forces at BR, N=25

Table F4: Tests for normality of anterior/posterior (X) shoulder forces at BR, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Shoulder X BR	.140	18	.200*	.976	18	.902

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Compressive/distraction (Y) shoulder forces at MER (-39.5 N ± 187.04, N = 25), expressed as a percent of height and weight, with a Skewness of α_3 = -2.24 (*SEskew = .481*) and Kurtosis of α_4 = 4.45 (*SEkurt = .935*) (Figure F5, Table F5).

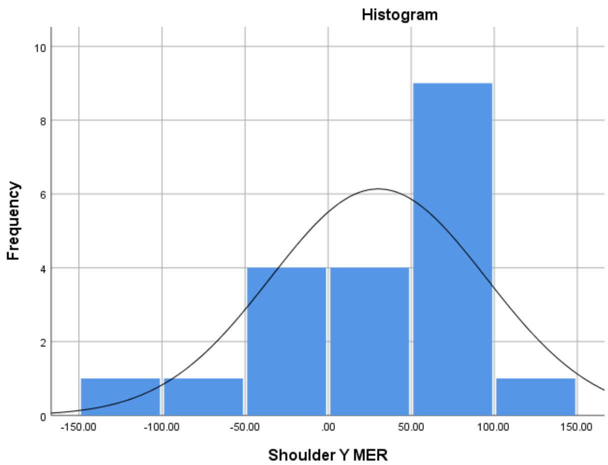


Figure F5: Normal distribution of compression/distraction (Y) shoulder forces at MER, N=25

Table F5: Tests for normality of compression/distraction (Y) shoulder forces at MER, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Shoulder Y MER	.160	20	.195	.933	20	.173

a. Lilliefors Significance Correction

Compressive/distraction (Y) shoulder forces at BR (-111.1 N ± 154.4, *N* = 25), expressed as a percent of height and weight, with a Skewness of α_3 = -.80 (*SEskew* = *.481*) and Kurtosis of α_4 = .68 (*SEkurt* = *.935*) (Figure F6, Table F6).

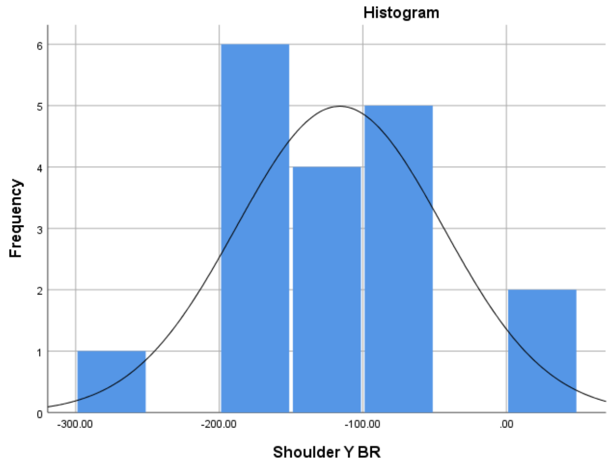


Figure F6: Normal distribution of compression/distraction (Y) shoulder forces at BR, N=25

Table F6: Tests for normality of compression/distraction (Y) shoulder forces at BR, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Shoulder Y BR	.135	18	.200*	.955	18	.512

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Abduction/adduction (Z) shoulder forces at MER (-133.9.6 N ± 262.5, *N* = 25), expressed as a percent of height and weight, with a Skewness of α_3 = .23 (*SEskew = .481*) and Kurtosis of α_4 = .66 (*SEkurt = .935*) (Figure F7, Table F7).

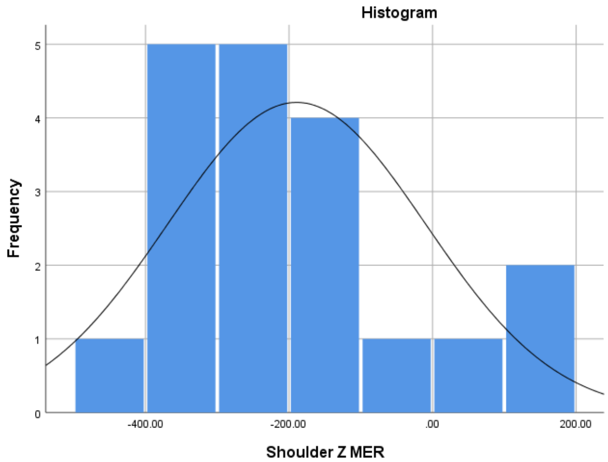


Figure F7: Normal distribution of abduction/adduction (Z) shoulder forces at MER, N=25

Table F7: Tests for normality of abduction/adduction (Z) shoulder forces at MER, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Shoulder Z MER	.128	19	.200*	.935	19	.210

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Abduction/adduction (Z) shoulder forces at BR (-255.6 N ± 193.4, *N* = 26), expressed as a percent of height and weight, with a Skewness of α_3 = -.91 (*SEskew* = *.481*) and Kurtosis of α_4 = 1.84 (*SEkurt* = *.935*). (Figure F8, Table F8).

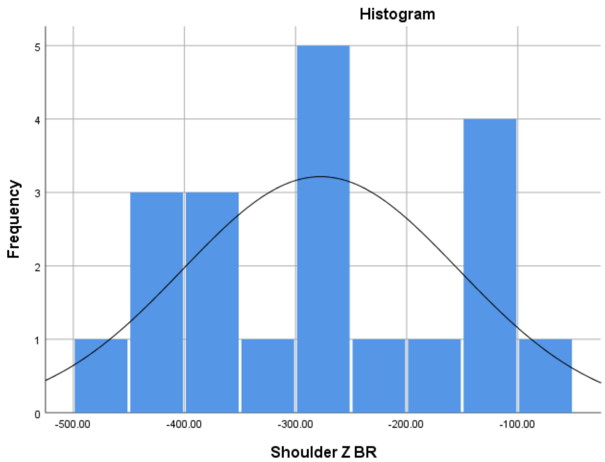


Figure F8: Normal distribution of abduction/adduction (Z) shoulder forces at BR, N=25

Table F8: Tests for normality of abduction/adduction (Z) shoulder forces at BR, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Shoulder Z BR	.109	20	.200*	.944	20	.290

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Cocking phase

Anterior/posterior (X) shoulder forces during the cocking phase rendered a normal distribution (143.9 N ± 160.1, *N*=25) with a Skewness of α_3 = -.270 (*SEskew = .481*) and Kurtosis of α_4 = .146 (*SEkurt = .935*) (Figure F9, Table F9).

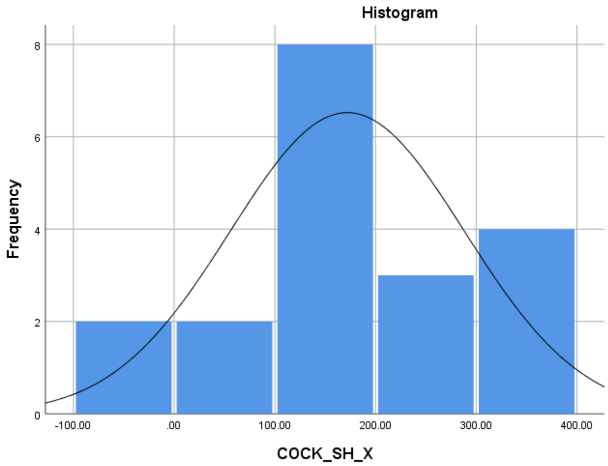


Figure F9: Normal distribution of anterior/posterior (X) shoulder forces during the cocking phase, N=25

Table F9: Tests for normality of anterior/posterior (X) shoulder forces during the cocking phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
COCK_SH_X	.108	19	.200*	.967	19	.720

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Compression/distraction (Y) shoulder forces during the cocking phase rendered a normal distribution (37.7 N ± 84.0, *N*=25) with a Skewness of α_3 = -.494 (*SEskew = .481*) and Kurtosis of α_4 = -.046 (*SEkurt = .935*) (Figure F10, Table F10).

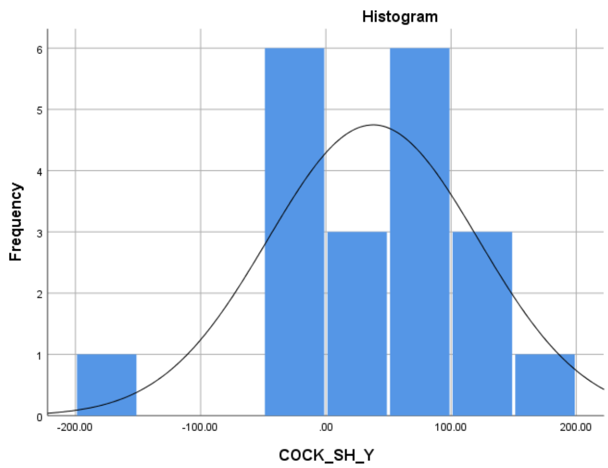


Figure F10: Normal distribution of compression/distraction (Y) shoulder forces during the cocking phase, N=25

Table F10: Tests for normality of compression/distraction (Y) shoulder forces during the cocking phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
COCK_SH_Y	.102	20	.200*	.945	20	.301

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Abduction/adduction (Z) shoulder forces during the cocking phase rendered a normal distribution (-191.7 N ± 266.4, *N*=25) with a Skewness of α_3 = .170 (*SEskew = .481*) and Kurtosis of α_4 = .242 (*SEkurt* = .953) (Figure F11, Table F11).

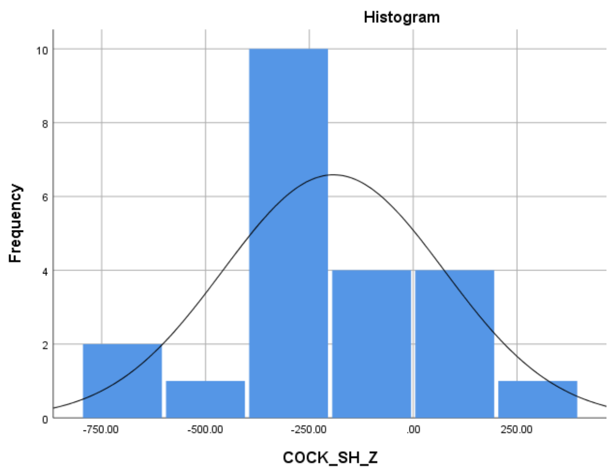


Figure F11: Normal distribution of abduction/adduction (Z) shoulder forces during the cocking phase, N=25

Table F11: Tests for normality of abduction/adduction (Z) shoulder forces during the cocking phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
COCK_SH_Z	.130	22	.200*	.965	22	.588

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Acceleration phase

Anterior/posterior (X) shoulder forces during the acceleration phase rendered a normal distribution (-144.7 N ± 393.9, *N*=25) with a Skewness of α_3 = .056 (*SEskew = .481*) and Kurtosis of α_4 = -1.23 (*SEkurt = .935*) (Figure F12, Table F12).

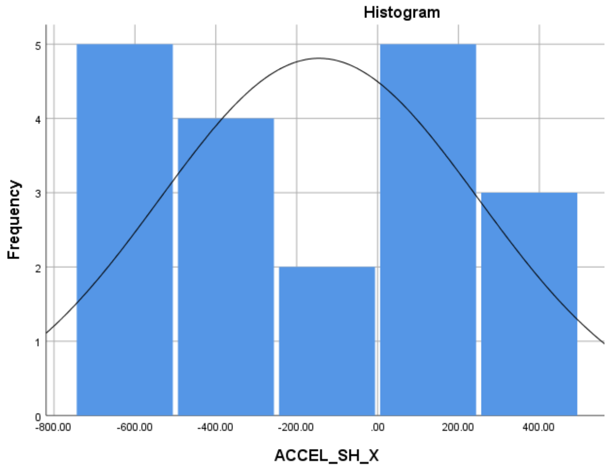


Figure F12: Normal distribution of anterior/posterior (X) shoulder forces during the acceleration phase, N=25

Table F12: Tests for normality of anterior/posterior (X) shoulder forces during the acceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ACCEL_SH_X	.174	19	.131	.936	19	.221

a. Lilliefors Significance Correction

Compression/distraction (Y) shoulder forces during the acceleration phase rendered a normal distribution (-207.7 N ± 250.1, *N*=25) with a Skewness of α_3 = -.024 (*SEskew = .481*) and Kurtosis of α_4 = -.476 (*SEkurt = .935*) (Figure F13, Table F13).

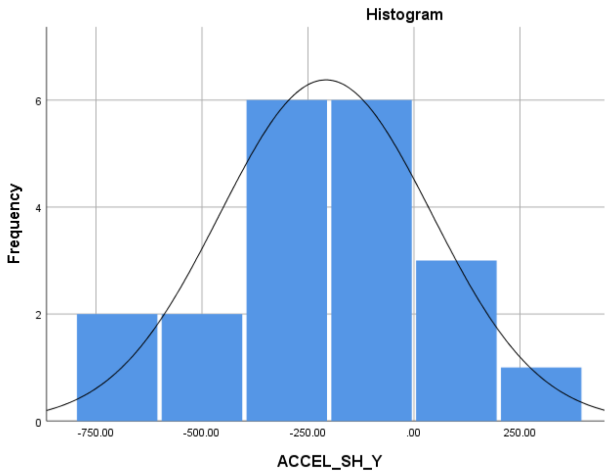


Figure F13: Normal distribution of compression/distraction (Y) shoulder forces during the acceleration phase, N=25

Table F13: Tests for normality of compression/distraction (Y) shoulder forces during the acceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ACCEL_SH_Y	.134	20	.200*	.970	25	.751

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Abduction/adduction (Z) shoulder forces during the acceleration phase rendered a normal distribution (-431.9 N ± 48.9, *N*=25) with a Skewness of α_3 = 1.00 (*SEskew* = *.481*) and Kurtosis of α_4 = -.021 (*SEkurt* = *.935*) (Figure F14, Table F14).

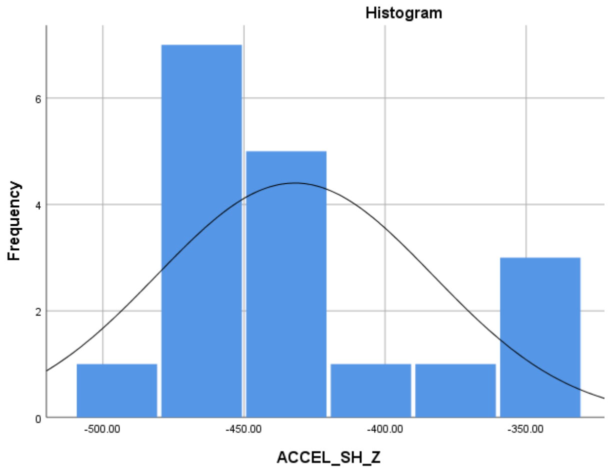


Figure F14: Normal distribution of abduction/adduction (Z) shoulder forces during the acceleration phase, N=25

Table F14: Tests for normality of abduction/adduction (Z) shoulder forces during the acceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ACCEL_SH_Z	.256	18	.003	.867	24	.016

a. Lilliefors Significance Correction

Deceleration phase

Anterior/posterior (X) shoulder forces during the deceleration phase rendered a normal distribution (-457.1.7 N ± 42.2, *N*=25) with a Skewness of α_3 = .905 (*SEskew = .481*) and Kurtosis of α_4 = .188 (*SEkurt = .935*) (Figure F15, Table F15).

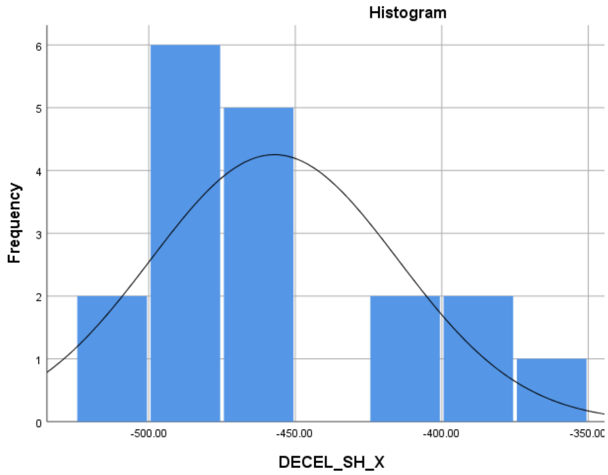


Figure F15: Normal distribution of anterior/posterior (X) shoulder forces during the deceleration phase, N=25

Table F15: Tests for normality of anterior/posterior (X) shoulder forces during the deceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DECEL_SH_X	.244	18	.006	.886	24	.033

a. Lilliefors Significance Correction

Compression/distraction (Y) shoulder forces during the deceleration phase rendered a normal distribution (-249.6 N ± 275.8, *N*=23) with a Skewness of α_3 = .601 (*SEskew = .481* = .481) and Kurtosis of α_4 = -.137 (*SEkurt = .935*) (Figure F16, Table F16).

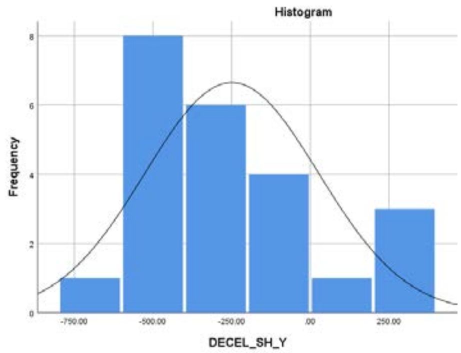


Figure F16: Normal distribution of compression/distraction (Y) shoulder forces during the deceleration phase, N=25

Table F16: Tests for normality of compression/distraction (Y) shoulder forces during the deceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DECEL_SH_Y	.140	23	.200*	.935	24	.142

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Abduction/adduction (Z) shoulder forces during the deceleration phase rendered a normal distribution (-316.1 N ± 129.6, *N*=25) with a Skewness of α_3 = .381 (*SEskew = .481*) and Kurtosis of α_4 = -.899 (*SEkurt = .935*) (Figure F17, Table F17).

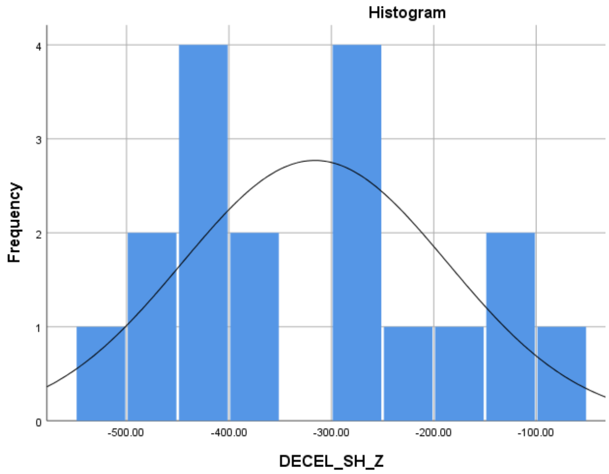


Figure F17: Normal distribution of abduction/adduction (Z) shoulder forces during the deceleration phase, N=25

Table F17: Tests for normality of abduction/adduction (Z) shoulder forces during the deceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DECEL_SH_Z	.151	18	.200*	.951	24	.443

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Research Question 2 Normality

Anterior/posterior (X) elbow forces at MER (29.9 N ± 114.5, *N* = 25), expressed as a percent of height and weight, with a Skewness of α_3 = -1.11 (*SEskew* = *.481*) and Kurtosis of α_4 = 4.83 (*SEkurt* = *.935* (Figure F18, Table F18).

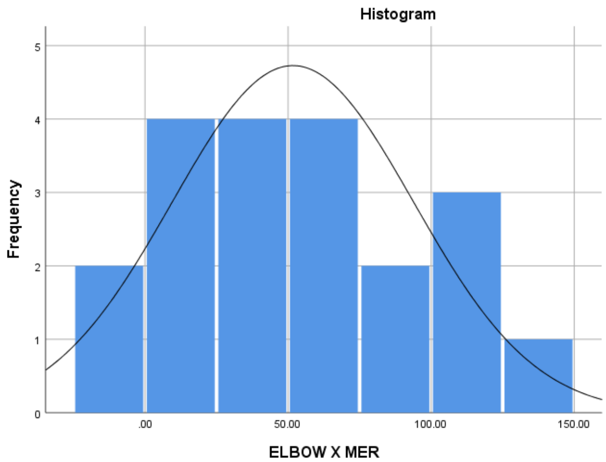


Figure F18: Normal distribution of anterior/posterior (X) elbow forces at MER, N=25

Table F18: Tests for normality of anterior/posterior (X) elbow forces at MER, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ELBOW X MER	.102	20	.200*	.963	24	.599

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Anterior/posterior (X) elbow forces at BR (14.4 N ± 156.5, *N* = 25), expressed as a percent of height and weight, with a Skewness of α_3 = .932 (*SEskew* = *.481*) and Kurtosis of α_4 = .605 (*SEkurt* = *.935*). (Figure F19, Table F19).

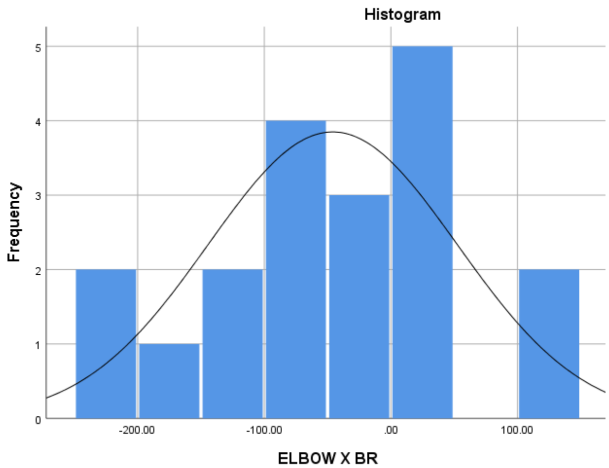


Figure F19: Normal distribution of anterior/posterior (X) elbow forces at BR, N=25

Table F19: Tests for normality of anterior/posterior (X) elbow forces at BR, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ELBOW X BR	.119	19	.200*	.978	24	.919

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Compressive/distraction (Y) elbow forces at MER (106.4 N ± 159.3, N = 26), expressed as a percent of height and weight, with a Skewness of α_3 = 2.10 (*SEskew = .481*) and Kurtosis of α_4 = 5.34 (*SEkurt = .935*). (Figure F20, Table F20).

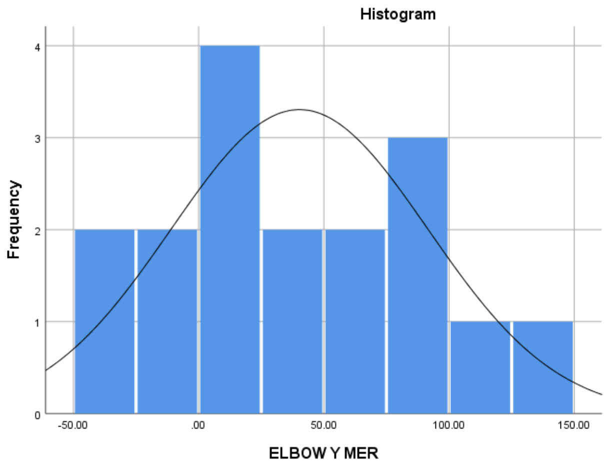


Figure F20: Normal distribution of compressive/distraction (Y) elbow forces at MER, N=25

Table F20: Tests for normality of compressive/distraction (Y) elbow forces at MER, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ELBOW Y MER	.136	17	.200*	.956	24	.560

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Compressive/distraction (Y) elbow forces at BR (306.2 N ± 271.7, N = 25), expressed as a percent of height and weight, with a Skewness of α_3 = 1.30 (*SEskew = .481*) and Kurtosis of α_4 = 1.70 (*SEkurt = .935*). (Figure F21, Table F21).

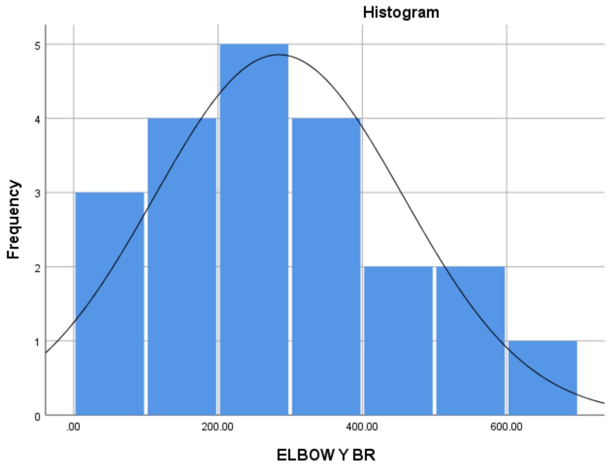


Figure F21: Normal distribution of compressive/distraction (Y) elbow forces at BR, N=25

Table F21: Tests for normality of compressive/distraction (Y) elbow forces at BR, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ELBOW Y BR	.117	21	.200*	.948	24	.317

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Varus/valgus (Z) elbow forces at MER (-85.6 N ± 91.3, N = 25), expressed as a percent of height and weight, with a Skewness of α_3 = .255 (*SEskew = .481*) and Kurtosis of α_4 = .369 (*SEkurt = .935*). (Figure F22, Table F22).

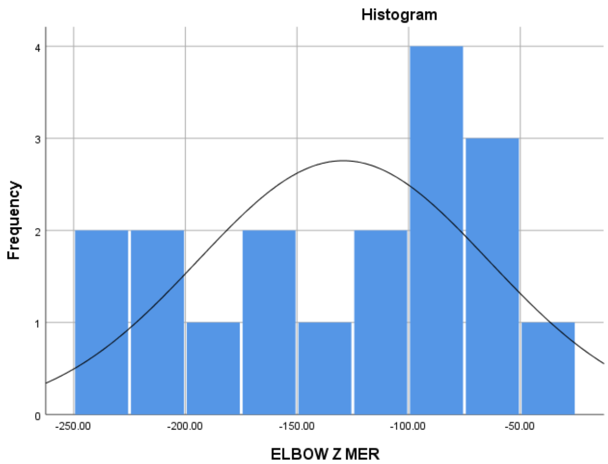


Figure F22: Normal distribution of varus/valgus (Z) elbow forces at MER, N=25

Table F22: Tests for normality of varus/valgus (Z) elbow forces at MER, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ELBOW Z MER	.169	18	.187	.916	24	.110

a. Lilliefors Significance Correction

Varus/Valgus (Z) elbow forces at BR (-108.4 N ± 148.1, N = 25), expressed as a percent of height and weight with a Skewness of α_3 = -.180 (*SEskew = .481*) and Kurtosis of α_4 = -.675 (*SEkurt = .935*). (Figure F23, Table F23).

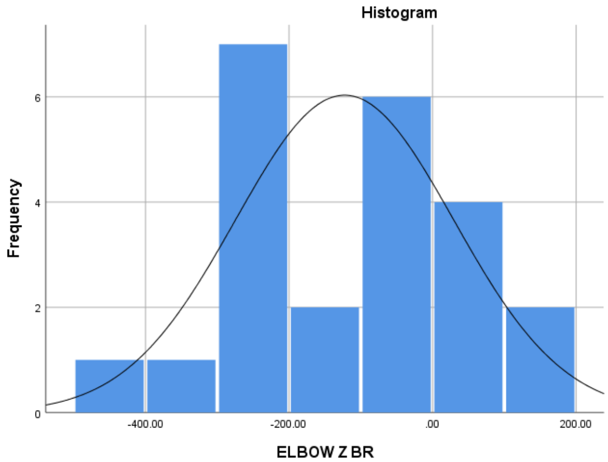


Figure F23: Normal distribution of varus/valgus (Z) elbow forces at BR, N=25

Table F23: Tests for normality of varus/valgus (Z) elbow forces at BR, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ELBOW Z BR	.135	23	.200*	.968	24	.643

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Cocking phase

Anterior/posterior (X) elbow forces during the cocking phase rendered a normal distribution (84.7 N ± 76.1, N=25) with a Skewness of α_3 = .197 (*SEskew* = *.481*) and Kurtosis of α_4 = .142 (*SEkurt* = *.935*) (Figure 24, Table F24).

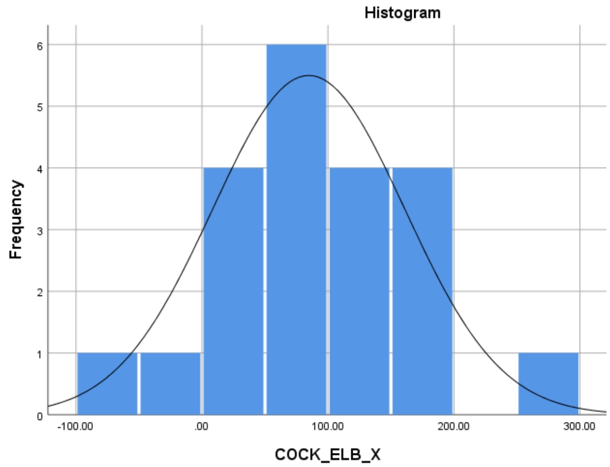


Figure F24: Normal distribution of anterior/posterior (X) elbow forces during the cocking phase, N=25

Table F24: Tests for normality of anterior/posterior (X) elbow forces during the cocking phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
COCK_ELB_X	.082	21	.200*	.989	24	.997

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Compression/distraction (Y) elbow forces during the cocking phase rendered a normal distribution (81.9 N ± 97.9, *N*=25) with a Skewness of α_3 = .815 (*SEskew = .481*) and Kurtosis of α_4 = -.057 (*SEkurt = .935*) (Figure F25, Table F25).

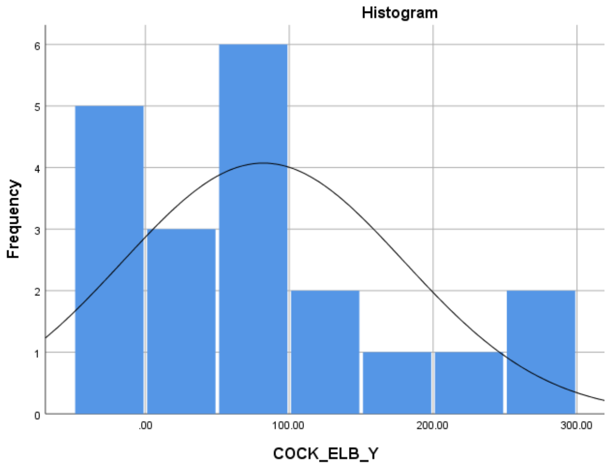


Figure F25: Normal distribution of compression/distraction (Y) elbow forces during the cocking phase, N=25

Table F25: Tests for normality of compression/distraction (Y) elbow forces during the cocking phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
COCK_ELB_Y	.172	20	.122	.905	25	.050

a. Lilliefors Significance Correction

Varus/valgus (Z) elbow forces during the cocking phase rendered a normal distribution (-116.1 N ± 76.1, *N*=25) with a Skewness of α_3 = -.361 (*SEskew* = *.481*) and Kurtosis of α_4 = -.655 (*SEkurt* = *.935*) (Figure F26, Table F26).

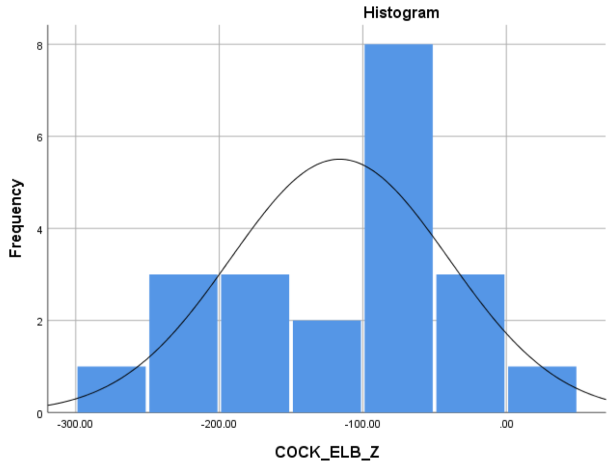


Figure F26: Normal distribution of varus/valgus (Z) elbow forces during the cocking phase, N=25

Table F26: Tests for normality of varus/valgus (Z) elbow forces during the cocking phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
COCK_ELB_Z	.183	21	.066	.955	24	.421

a. Lilliefors Significance Correction

Acceleration phase

Anterior/posterior (X) elbow forces during the acceleration phase rendered a normal distribution (6.38 N ± 225.3, N=25) with a Skewness of α_3 = -.194 ($SEskew$ = $.481$) and Kurtosis of α_4 = -1.32 ($SEkurt$ = $.935$) (Figure 27, Table F27).

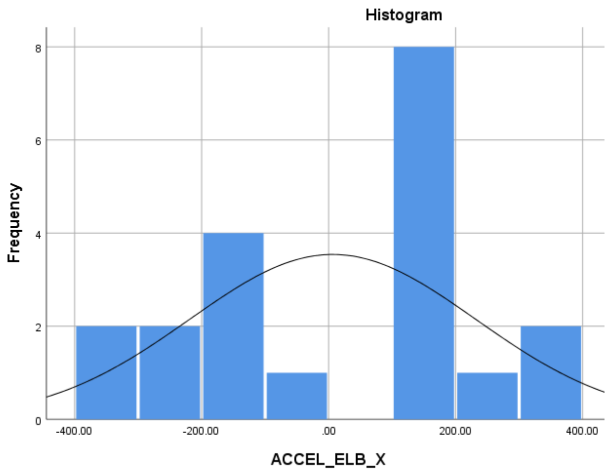


Figure F27: Normal distribution of anterior/posterior (X) elbow forces during the acceleration phase, N=25

Table F27: Tests for normality of anterior/posterior (X) elbow forces during the acceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ACCEL_ELB_X	.246	20	.003	.910	24	.065

a. Lilliefors Significance Correction

Compression/distraction (Y) elbow forces during the acceleration phase rendered a normal distribution (391.7 N ± 220.3, *N*=25) with a Skewness of α_3 = .755 (*SEskew = .481*) and Kurtosis of α_4 = .483 (*SEkurt = .935*) (Figure F28, Table F28).

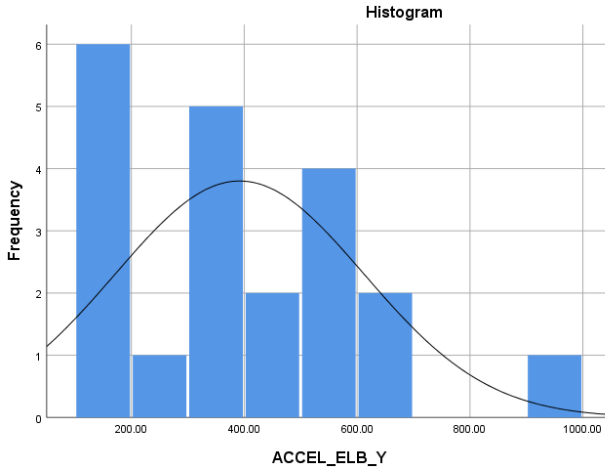


Figure F28: Normal distribution of compression/distraction (Y) elbow forces during the acceleration phase, N=25

Table F28: Tests for normality of compression/distraction (Y) elbow forces during the acceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ACCEL_ELB_Y	.124	21	.200*	.928	24	.126

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Varus/valgus (Z) elbow forces during the cocking phase rendered a normal distribution (-229.6 N ± 24.7, *N*=25) with a Skewness of α_3 = -.312 (*SEskew* = *.481*) and Kurtosis of α_4 = -1.51 (*SEkurt* = *.935*) (Figure F29, Table F29).

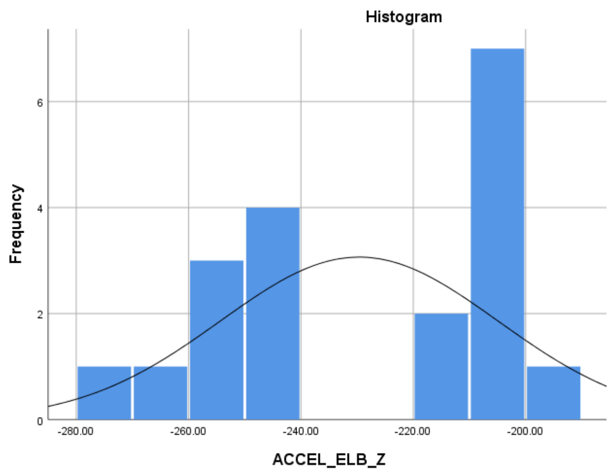


Figure F29: Normal distribution of varus/valgus (Z) elbow forces during the acceleration phase, N=25

Table F29: Tests for normality of varus/valgus (Z) elbow forces during the acceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ACCEL_ELB_Z	.235	19	.007	.860	24	.010

a. Lilliefors Significance Correction

Deceleration phase

Anterior/posterior (X) elbow forces during the deceleration phase rendered a normal distribution (-173.5 N ± 92.1, *N*=25) with a Skewness of α_3 = .244 (*SEskew = .481*) and Kurtosis of α_4 = -.202 (*SEkurt = .935*) (Figure 27, Table F27).

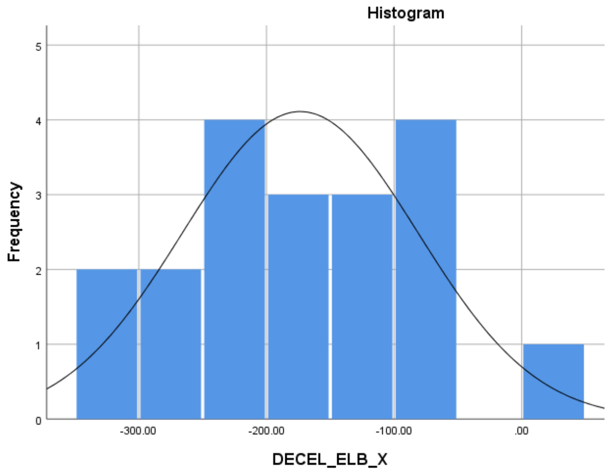


Figure F30: Normal distribution of anterior/posterior (X) elbow forces during the deceleration phase, N=25

Table F30: Tests for normality of anterior/posterior (X) elbow forces during the deceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DECEL_ELB_X	.158	19	.200*	.956	24	.501

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Compression/distraction (Y) elbow forces during the deceleration phase rendered a normal distribution (388.8 N ± 194.9, *N*=25) with a Skewness of α_3 = .247 (*SEskew = .481*) and Kurtosis of α_4 = .083 (*SEkurt = .935*) (Figure F31, Table F31).

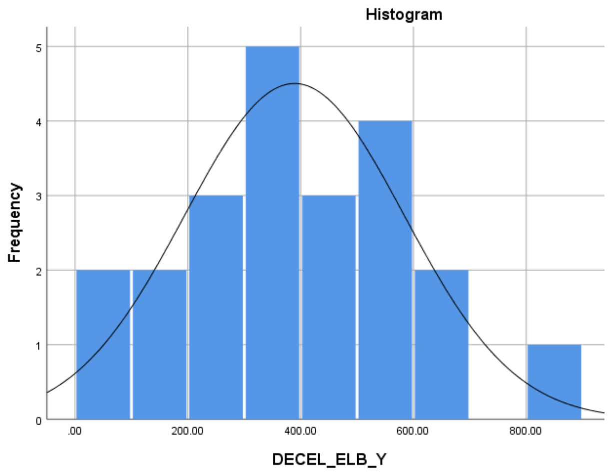


Figure F31: Normal distribution of compression/distraction (Y) elbow forces during the deceleration phase, N=25

Table F31: Tests for normality of compression/distraction (Y) elbow forces during the deceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DECEL_ELB_Y	.103	22	.200*	.976	24	.843

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Varus/valgus (Z) elbow forces during the cocking phase rendered a normal distribution (-235.9 N ± 118.4, *N*=25) with a Skewness of α_3 = .066 (*SEskew = .481*) and Kurtosis of α_4 = -.523 (*SEkurt = .935*) (Figure F32, Table F32).

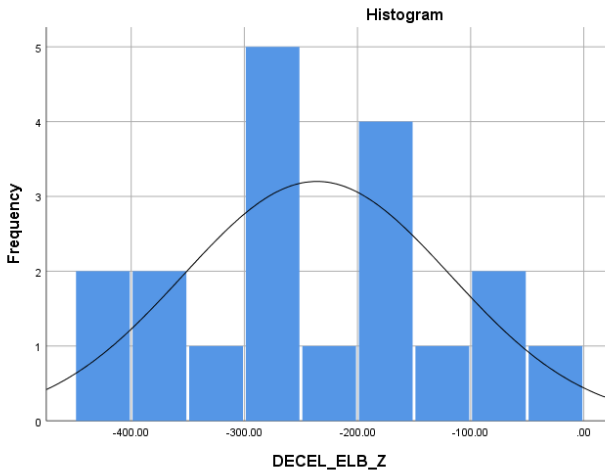


Figure F32: Normal distribution of varus/valgus (Z) elbow forces during the deceleration phase, N=25

Table F32: Tests for normality of varus/valgus (Z) elbow forces during the deceleration phase, N=25

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DECEL_ELB_Z	.124	19	.200*	.973	24	.828

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Research Question 3 Normality

Ball speed rendered a normal distribution (63.47 ± 25.2, *N*=25) with a Skewness of α_3 = .066 (*SEskew* = *.481*) and Kurtosis of α_4 = -.523 (*SEkurt* = *.935*) (Figure F32, Table F32).

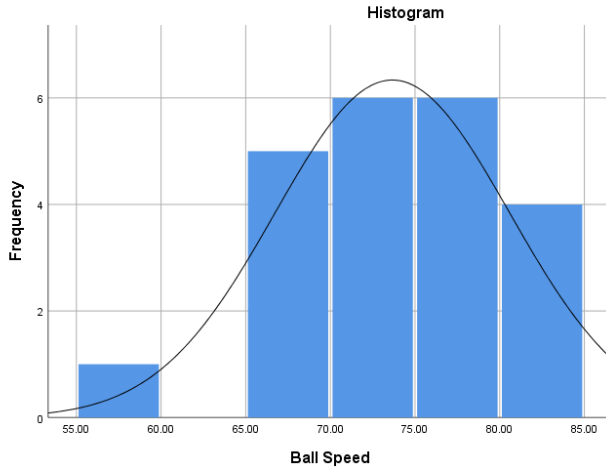


Figure F33: Normal distribution of ball speed, N=25

Research Question 4 Normality

Ball spin rendered a normal distribution (1508.9 rpm ± 612.7, *N*=25) with a Skewness of α_3 = -.133 (*SEskew = .481* = .512) and Kurtosis of α_4 = -.009 (*SEkurt = .935* = .992) (Figure F34, Table F34).

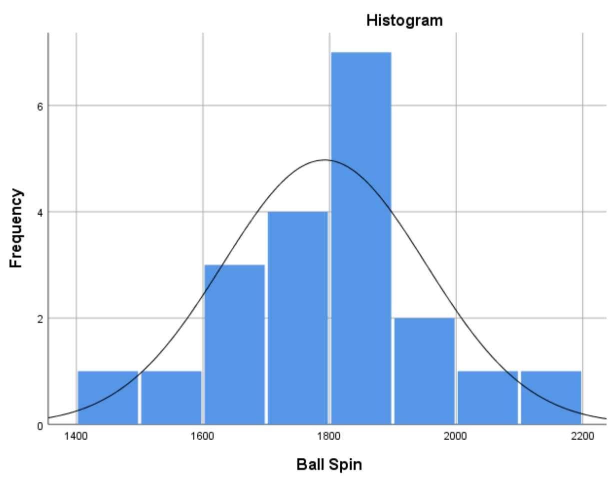


Figure F32: Normal distribution of ball spin, N=25