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Division I Collegiate Baseball Pitching Performance in Relation to Forearm Kinematics and Kinetics

Christopher W. Watson

DIVISION I COLLEGIATE BASEBALL PITCHING PERFORMANCE IN RELATION TO FOREARM KINEMATICS AND KINETICS

by

Chris W. Watson CSCS

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Chris W. Watson

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Master of Science in Kinesiology, Sports Performance Conc.

Mu Qiao
Supervisor of Thesis Research

David J. Szymanski

David Joseph Szymanski
Head of Kinesiology

Members of the Thesis Committee:
Mu Qiao
David J. Szymanski
Ryan L. Crotin

Approved:

Henrietta Williams Pichon

Henrietta Williams Pichon
Dean of Education and Human Sciences

Approved:

Ramu Ramachandran

Ramu Ramachandran
Dean of the Graduate School

GS Form 13
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ABSTRACT

This thesis investigates physical and anthropometric factors influenced by forearm rotation biases associated with supination and pronation on pitch characteristics among Division I college baseball pitchers. The study involved twenty-two participants who underwent comprehensive physical assessments, including measures of forearm strength, range of motion, and grip strength, as well as finger and hand length measurements. Ball flight metrics were collected during intrasquad scrimmages using advanced radar tracking technology. Results revealed significant relationships between distinct physical biases of strength in pronation and supination, pinch strength, anthropometrics such as middle finger length, and specific pitch characteristics. This study lays the groundwork for future research exploring individualized coaching strategies tailored to pitchers' unique profiles, outlining potential opportunities for maximizing performance potential and minimizing injury risk.

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Author ______________________________

Date ______________________________

DEDICATION

I am grateful to Dr. Qiao, Dr. Szymanski and Dr. Crotin for their constant support, guidance and expertise. Their mentorship has been invaluable in my academic and personal growth. I am also thankful for the Louisiana Tech Baseball team for being coachable, allowing me to develop great relationships with them and being so enjoyable to work with. Additionally, I also appreciate the coaching staff for trusting me, allowing me to meaningfully contribute to the team and for sharing their wealth of knowledge which I have greatly learned from.

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KEY TO ABBREVIATIONS

ANOVA	Analysis of Variance
ER	External Rotation
FPM	Flexor Pronator Mass
IR	Internal Rotation
MER	Maximal External Rotation
MPH	Miles Per Hour
SFC	Stride Foot Contact
ROM	Range of Motion
RPM	Revolutions per Minute
UCL	Ulnar Collateral Ligament

CHAPTER 1

INTRODUCTION

The success of a baseball pitcher is influenced by many different factors, such as unique anthropometrics, ranges of motion (ROM), muscular strength and power, biomechanical differences, and motor preferences throughout pitching motions. Among these characteristics, the amount of forearm supination and pronation at ball release impacts a pitcher's success. Forearm supination and pronation occur in different phases of the pitching sequence; however, the degree and timing of each action are individualized from one athlete to another which changes the ball flight and possibly dictates the type of pitch used in games.

Recent technological advancements have enabled the quantitative assessment of pitch movement (Nathan, 2007), evaluating factors like ball velocity, release qualities, and spin characteristics such as spin rate, spin efficiency, and spin direction. Spin rate is measured in revolutions per minute (rpm) and relates to the potential movement of the pitch, spin direction as the direction ball movement will occur, and spin efficiency as the percentage of the spin rate that will contribute to movement from the baseball (Nathan, 2007). It has been theorized that a pitcher's forearm rotation strength and mobility in pronation and supination could influence their ability to execute various pitch types effectively. Change-ups and breaking balls include a variety of pitch types, each requiring specific cues and grips to achieve effectiveness. Change-ups are often taught to be thrown by pronating the forearm before releasing the baseball (Figure 1-2), while breaking balls, such as curveballs and sliders, require pitchers to supinate, rotating the forearm anteriorly into a thumbs-up position (Figure 1-3). Fastballs typically involve minimal forearm rotation, focusing more on achieving maximum pitch velocity (Figure 1-1). These movements allow the pitcher to release the ball with the desired sidespin, topspin, or both.

Figure 1-1: Four-seam fastball grip

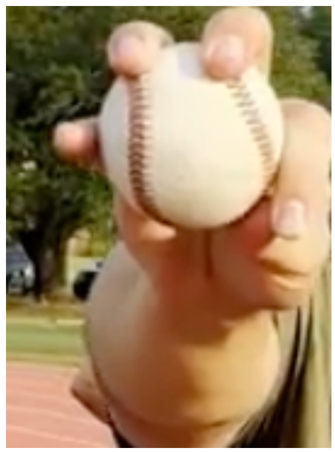

Figure 1-2: Change-up grip

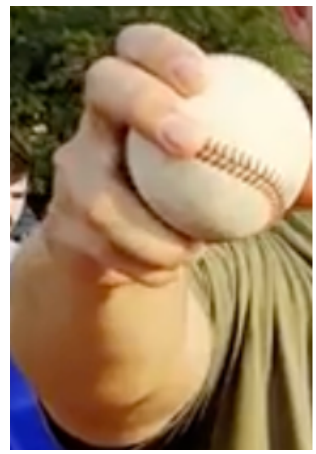

Figure 1-3: Breaking ball grip

Previous research has shown the failure of a cadaver's ulnar collateral ligament (UCL) to be approximately 34 N·m (Ahmad et al., 2003), and the calculated varus torque of professional pitchers at 120 N·m (Fleisig et al. 1995; Werner et al. 1993). The flexor pronator mass (FPM) has been heavily researched for its importance in providing valgus elbow stability in support of the UCL. It provides stability by resisting forces applied to the elbow joint and joint failure with a varus torque (Ahmad et al., 2003; Buffi et al. 2015; Davidson et al. 1995; Keeley et al. 2010; Werner et al. 1993). Further research could be critical in further understanding and reducing the occurrence of medial elbow injuries and "Tommy John Surgery". Despite increased awareness and injury prevention programs, medial elbow injuries have become more prevalent, with the primary injury shifting from the shoulder to the elbow (Conte et al., 2016). Tommy John Surgery has increased by 343% from 2003 to 2014 with high injury occurrence also happening to younger athletes (Mahure et al., 2016).

Isokinetic devices and handheld dynamometers have been used to measure the shoulder strength of the internal and external rotators. This has been accepted as important information for monitoring pitchers, enhancing performance, and reducing injury risk (Newsham et al., 1998). The use of dynamometers or isokinetic devices should also be considered for measuring forearm grip and rotation strength to identify a pitcher's potential for injury risk, and relationship to performance as well as monitoring fatigue over the season. Monitoring fastball velocity may be an inaccurate measure of fatigue (Crotin et al., 2013). Many pitchers increase velocity throughout the season or undergo mechanical compensation to maintain their velocity midgame. This compensation may come at the cost of altered loading patterns, cause additional strain on the medial elbow stabilizers, and increase the risk of injury. Measurement of strength numbers using a dynamometer can also be used to compare a pitcher's pre-game baseline strength to their post-game strength to determine fatigue or adaptation by investigating the difference in dominant and non-dominant arm strength (Crotin et al., 2021).

Forearm positioning while throwing influences on-field pitching performance in addition to injury prevention. The degree of pronation significantly increases both vertical and horizontal break of a thrown pitch, which has been shown to negatively influence a hitter's performance by increasing the distance of contact from the optimal ‘sweet spot’ of the bat (Higuchi et al., 2013). Pitchers' lack of pronation of the forearm while throwing later in games may be a reason that fastballs ‘flatten’ out, meaning having less total movement and being easier for players to hit (Solomito et al., 2017). Pitchers’ unique physical, anthropometric, and biomechanics qualities while throwing determine their ball flight and performance capabilities while also alter the loading patterns on the arm and the forces placed onto the joints.

Arm positioning while throwing is important in maximizing fastball velocity and regulating normalized medial elbow load. Despite similar levels of grip strength, collegiate pitchers who experienced greater valgus torque from pitching showed reduced recovery of the FPM muscles the following day compared to a group of pitchers with reduced valgus torque (McHugh et al., 2023). A lack of grip strength can impact the interaction between pitching velocity and normalized elbow torque that is expressed through the Biomechanical Efficiency Ratio. The Biomechanical Efficiency Ratio quantifies the extent of ball velocity that can be achieved relative to normalized elbow varus torque (Davis et al., 2009). This ratio exemplifies how the relationship between elbow torque and pitching velocity can be quantified and measured as greater pitching velocity per unit of normalized torque is desired. Throwing arm position has a great effect on biomechanical efficiency, as increased shoulder external rotation at stride foot contact (SFC) to avoid an ‘inverted W’, shoulder abduction exceeding 90° at SFC, and greater elbow flexion at SFC all significantly enhance biomechanical efficiency (Crotin et al., 2022).

The Stress Shielding Ratio of a pitcher compares their arm strength stabilizing and protecting the ligament relative to the loads placed upon it during pitching (Yanai et al., 2023). The Stress Shielding Ratio combined with Biomechanical Efficiency Ratio may indicate why pitchers fatigue at different rates. A decrease in forearm strength parallels a loss in the ability to withstand medial elbow torque that impacts dynamic elbow stability. As a result, the evaluation of forearm strength to monitor fatigue may help to adjust workload, determine when intervention is necessary, and help to prevent injuries.

Anthropometrics, such as finger length, arm segment lengths, and insertion points, as well as height and type of grip used to throw a baseball could determine the spin rate of a baseball, impacting the amount of friction and force that can be applied to the ball, force-tension relationships, motor preferences, and susceptibility to injury. Despite theories of pitching coaches and sports scientists, there are no agreed-upon anthropometric qualities researched to aid coaches and sports performance staff in identifying pitchers who can effectively throw different pitch types. There is a lack of public research, knowledge of training considerations, motor preferences, anthropometric, and biomechanical predictors of increased spin rates, ball movement, and injury prevention strategies. This information would greatly benefit teams in talent identification, reduction of injuries, and determination of player development programs.

Many different factors are believed to impact ball flight of a thrown pitch, including spin metrics, physical traits, anthropometric factors, and biomechanics. This study aims to provide information that addresses the gap of evidence-based information on the relationships of how forearm pronation/supination range of motion and isokinetic strength, handgrip strength, pinch grip strength, and anthropometric factors impact pitchers' ball flight characteristics. This study aims to offer a comprehensive analysis of how forearm pronation or supination biases and medial elbow dynamic stabilizer strength influence pitching performance. Regarding physical traits, the hypotheses is as follows: (1) Pitchers with a forearm supination bias—characterized by greater Biodex isokinetic strength and ROM in supination—are expected to have a higher spin rate on their breaking ball and lower spin efficiency on their fastball; (2) conversely, pitchers with a forearm pronation bias—indicated by greater Biodex isokinetic strength and ROM in pronation—are expected to demonstrate a larger change-up spin direction deviation (SDD) and higher spin efficiency on their fastball. The hypotheses for anthropometric data include (3) pitchers with longer index finger, middle finger, and thumb, and (4) greater middle/index finger discrepancy will have increased breaking ball spin rates. Hypotheses for forearm grip strength consist of (5) pitchers with greater grip strength will have increased breaking ball spin rates, and (6) greater grip strength will correlate with greater strength in forearm supination and pronation.

CHAPTER 2

BACKGROUND

2.1 Ball Flight

2.1.1 Spin Rate

The spin rate determines the potential amount of movement in a pitch through the Magnus effect (Nathan, 2007). Fastballs with increased spin rate have a greater aerodynamic impact on the ball, pushing the air downward, reducing the downward trajectory from gravity, and create a rising illusion effect on the hitter's eyes (Nathan, 2007). The summation of wrist strength (flexion and extension), time to wrist extension strength, and radial deviation strength also impact spin and have been significant predictors of fastball spin rate (Wong et al. 2021). Right around the instant of ball release, the fingers flex immediately, applying force to the ball at over 80 percent of measured finger strength (Matsuo et al., 2018; Kinoshita et al., 2017). Pine tar and other sticky substances, such as Spider Tack, are the only known way to increase spin rate, but were banned by Major League Baseball in 2021 as a form of cheating. Fastball velocity has the greatest association to spin rate (Nagami et al., 2011), with the spin rate increasing proportional to velocity; however, most studies overlook this relationship. Spin velocity ratio (Belisario et al., 2022), calculated by dividing pitch velocity (mph) by spin rate (rpm), is the most beneficial evaluation of fastball spin rate.

2.1.2 Spin Direction

Spin direction (also known as "tilt") measures the orientation of ball rotation after it has been released by the pitcher (Nathan, 2007). This determines the direction of movement the ball will travel and uses an hour-and-minute measurement system. For fastballs, spin direction is usually dependent on the location of release. Higher release points result in more 'north to south' vertical movement (closer to 12:00), while low release points cause 'east to west' horizontal movement (closer to 3:00 for right-handed pitchers and 9:00 for left-handed pitchers). Other pitch types rely heavily on the rotation of the forearm to manipulate the direction of pitch movement. Breaking balls use different degrees of supination to get on the outside, front, or both of the baseball, creating side and topspin. Change-ups require forearm pronation, a shift in force application to the inside of the baseball, reducing velocity, and creating a 'fading' movement to the arm side of the pitcher. Effective change-ups would have greater movement separation from their fastball and a larger spin direction deviation. For example, a pitcher having a fastball with a spin direction of 1:00 would have a greater amount of movement on a 2:00 change-up than a change-up with a spin direction of 1:30.

2.1.3 Spin Efficiency

Spin efficiency is expressed as a percentage and is the ratio of active spin to the spin rate of a pitch. Active spin is what contributes to the Magnus effect and pitch movement (Nathan, 2007). Although spin efficiency varies for different pitch types, percentages close to 1:00 are generally optimal for four-seam fastballs. Pronation-dominant pitchers are expected to have greater spin efficiencies, benefitting from the additional impact of the Magnus effect, and greater total movement on their fastball (Keeley et al., 2010). Alternatively, a supination-dominant pitcher may struggle to achieve high spin efficiency on their fastball and may choose to throw more fastball variations such as cutters or two-seam fastballs, benefiting from seam-shifted wake effects where the smooth surface and seams of the baseball interact with the air to create unexpected movement (Smith et al., 2021).

2.2 Physical Traits

2.2.1 Forearm Rotation - Pronation/Supination

The incidence of forearm and elbow injuries has been increasing over the last three to four decades, with not only more occurrences, but also at younger ages. According to Fleisig et al. (2009), UCL surgeries performed on high school athletes in his clinic increased from 7% (9 out of 112) of total UCL surgeries between 1994 and 1998 to 26% (179 out of 512) from 2004 to 2008. This alarming trend continues to escalate (Ciccotti et al., 2017). Understanding the biomechanics of forearm rotation is crucial in comprehending the forces acting on the UCL and surrounding structures. The muscles of the medial elbow, UCL, and osseous articulations (joints where bones come together) resist the valgus load with a varus moment during throws and are susceptible to failure from repeated microdamage. The UCL has articulations between the proximal radius, proximal ulna, and distal humerus. Joint stability is also provided by the skeletal system in the humerus' trochlea and the ulna’s olecranon. Other than the FPM, additional muscles involved in elbow motion are the biceps brachii, brachialis, brachioradialis, and triceps brachii (Werner et al., 1993). The bicep muscles primarily manage elbow flexion and aid in forearm supination, whereas the triceps brachii plays a crucial role in elbow extension and forearm pronation. Elbow flexion leads to an increase of supination ROM and a reduction of pronation ROM, while the reverse effect is observed during elbow extension (Pereira et al., 2008; 37; Shaaban et al., 2008).

Cadaver research has shown that torque on the UCL is reduced by loading the FPM muscles to assist in stabilizing the ligament against valgus torque (Davidson et al 1995; Lin et al., 2007; Park et al., 2004; Tamura et al., 2023; Udall et al., 2009). Four muscles, the flexor carpi radialis, pronator teres, flexor digitorum superficialis, and flexor carpi ulnaris, make up the FPM and have an origin at the medial epicondyle and the anterior bundle of the UCL (Lin et al., 2007). Pronation and FPM contraction are essential for the production of varus torque to withstand tensile loading of the medial elbow (Fleisig et al., 1995; Pomianowski et al., 2001). The extensor-supinator mass is made up of the extensor carpi radialis longus, brevis, and brachioradialis (Lin et al., 2007). A computational simulation of pitching estimates that elbow muscles contribute 35-57% of maximum varus torque with the rest being applied passively to the UCL and joint capsule (Yanai et al.,2023). In vivo research has revealed that applying valgus torque to the elbow causes the ulnohumeral space to widen and the sublime tubercle to shift laterally (Otashi et al., 2014). Forearm pronation and palmar flexion decreases joint space and shifts the sublime tubercle medially to shield the UCL. Similar to valgus torque, finger flexion and wrist ulnar flexion increase the joint space and cause the sublime tubercle to move laterally (Otashi et al. 2014; Shitara et al. 2021; Tamura et al. 2023). A balance is needed for joint mobility for proper ROM and mechanics as well as joint stability from well-coordinated and strong muscles to prevent injury (Fleisig et al., 1995).

2.2.2 Impact of Supination on the Forearm

Throwing breaking pitches carries an inherent injury risk (Solomito et al., 2017). While forearm supination during breaking ball delivery does not directly increase torque, it positions the forearm in a way that limits the FPM capacity to generate varus torque and stabilize the medial elbow (Buffi et al., 2015; Otashi et al., 2014; Solomito et al., 2017). Specifically, a 1 N·m increase in the supination moment leads to a 1 N·m rise in elbow varus moment for a fastball and 1.1 N·m for a curveball (Solomito et al., 2017). The increase in supination requires additional stretch of the pronator muscles and contraction of the FPM. This could create additional strain on the medial elbow (Solomito et al., 2017). Forearm supination, wrist ulnar flexion, middle and index finger flexion are fundamental movements necessary for throwing a breaking ball. These movements increase the ulnohumeral joint space, leaving the elbow more vulnerable to injury (Otashi et al., 2014; Tamura et al., 2023). This evidence supports the frequent occurrence of forearm FPM fatigue among pitchers after throwing breaking balls, potentially increasing their likelihood of injury from excessive supination.

2.2.3 Forearm Rotation Adaptation

Research has investigated the substantial ROM adaptation in the throwing shoulder of pitchers. This includes hypothesizing changes in humeral retroversion, bony adaptation, anterior capsular laxity, posterior capsule tightness, and repetitive eccentric activity causing increased glenohumeral external rotation (ER) and decreased glenohumeral internal rotation (IR) (Laudner et al., 2013; Reinold et al., 2008). Professional pitchers show significant reductions in IR ROM immediately after pitching and 24 hours later (Reinold et al., 2008). Additionally, significant changes occur in the elbow joint including a decrease of 3.2° in elbow extension ROM immediately after pitching, with a 2.6° reduction observed after 24 hours. Pitchers also exhibit diminished ROM in elbow flexion, forearm pronation and total arc of motion in their throwing arm relative to their non-dominant arm (Laudner et al., 2013; Wright et al., 2006). These limitations in ROM may stem from repeated medial elbow stress and could further explain why both vertical and horizontal breaks decrease with the reduced elbow extension that comes from fatigue.

Fleisig et al. (2009) demonstrated the significant impact of fatigue on injury, revealing a 36-times increase in the risk of injury among pitchers when fatigue occurs. Fatigue can induce alterations in the forearm and elbow, affecting ROM and strength deficits, thereby impacting pitching performance, joint loading, and increasing the risk of injury. Forearm rotation may have a similar mechanism of adaptation as the shoulder and could be responsible for the development of elbow injuries, such as instability, muscle strains, epicondylitis, osteochondritis, and neuropathy (Laudner et al., 2012). Increasing pronation at the forearm decreases the amount of available ER at the glenohumeral joint. Pronating the forearm increases the length and tension of the biceps (Kibler et al., 2022). The adaptation that occurs in the forearm soft tissue may impact the ulnohumeral joint in pronation/supination, the glenohumeral joint in ER as well as pitching mechanics and performance as a whole.

Adaptation of forearm rotation mechanics highlights the significance of forearm strengthening programs in mitigating injury risks and maintaining pitching performance. This is increasingly important with the recent pace of play rule changes reducing the amount of time in between pitches to 20 seconds. Fatigue modeling has shown that limiting time between pitches increases FPM muscle fatigue, reducing the amount of joint rotational stiffness, and additional stress placed on the UCL (Sonne et al., 2016). Increased pitch counts decrease elbow valgus stability with significantly increased medial elbow joint space after pitching. Using a goniometer to determine pronation/supination ROM as well as dynamometry to measure the strength of the forearm may be an effective monitoring approach for injury prevention by revealing increases in joint laxity and loss of medial elbow stability. This knowledge would provide on-field and performance coaches, as well as medical staff with insights focused on the biomechanical efficiency and stress-shielding capacity of pitchers, recovery status, and adaptation of a pitcher's throwing arm. In vivo knowledge from research is still lacking; however, the combination of inverse dynamics models through biomechanical analyses and muscular strength testing forms the best approach to individualize training. As well as throwing programs and competitive workloads to assist in protecting their throwing arms from joint failure during pitching.

2.3 Anthropometric Factors

2.3.1 Hand and Finger Length

Spin rate is impacted by the friction of the fingers against the ball surface and seams as it is released. Grip strength, finger length, and additional space between the ball and palm improve leverage, causing the ball to remain on the fingers longer and enhancing the application of force, spin rate, and potential movement to the baseball. The ring finger and thumb make minor contributions to force production, while the index and middle fingers produce the greatest amount of shear force from friction (Kinoshita et al. 2017). Friction can be altered by many factors such as changing the finger placement (on a seam vs no seam) or through optimal moisture levels, which can vary from person to person. Excessive moisture or dryness on finger pads can decrease friction, and the application of rosin in wet conditions has been shown to enhance friction (Zwart et al. 2021). There is also an issue of the relationship between blisters and repetitive finger friction which may prevent some pitchers from reaching their optimal spin rates (Zwart et al. 2021). Although there are many theories, there is currently a lack of research on anthropometric data as it relates to the spin rate of the baseball.

2.3.2 Arm Length, Joint Laxity and Insertion Points

There are individualized differences in the precise origin and insertion locations of the FPM muscles in each person. These locations also change based on the flexion of the arm and can be altered by different mechanics of pitching (Davidson et al., 1995; Pomianowski et al., 2001). The radius crosses over the ulna during forearm pronation, and the length of each bone may influence the movement capabilities of the forearm. Carrying angle is the angle formed by the long axis of the humerus and forearm when the arm is in the anatomical position and is an example of an anatomical measure that can alter the forearm ROM. This means that a smaller angle reduces forearm rotation in pronation and supination, while a larger angle increases it. An average male has a carrying angle of 11° of valgus; however, some professional baseball players have over 15° of valgus (Cain et al., 2003). Repetitive stress and microtrauma from pitching and overuse can cause stretching and weakening of the joint, increase joint laxity, and the risk of injury. Joint laxity can be evaluated by measuring active and passive ROM. Passive ROM typically increases more in individuals with greater joint laxity, enabling tissues to surpass their normal limits when force is applied.

Similarly, individual differences in arm length and insertion points also contribute to the complexities of pitching biomechanics. Pitchers with longer arm lengths may require less ‘arm speed’ or internal rotation velocity due to principles of angular velocity and the increased potential to create speed from longer levers. Longer limbs may also have an increased risk of injury, as torque and stress on the body due to a larger distance from the fulcrum may increase muscular effort to accelerate throwing arm segments, especially with heavier throwing arm mass. Research in youth pitchers has displayed this relationship as pitchers with longer upper extremities have increased elbow varus torque at the elbow and decreased elbow flexion at SFC (Downs et al., 2021). Individual variations alter joint lever arms, force-length relationships, and preferences of the athlete and that may impact the forearm ROM, strength, or ball flight and performance metrics of an individual (Soubeyrand et al., 2017).

2.3.3 Grip Width and Type Variables

Different factors of a pitcher's grip may alter spin rates and the movement of the pitch from the Magnus effect. The grip width used by a pitcher may alter the spin rate by the length the ball can roll off the fingers and the force that can be applied, in the same way as finger lengths. A closer fastball grip should increase spin rate as the ball can roll off the fingers for longer, remaining in contact with the fingers and allowing for an increased window for shear force to be applied (Belisario et al. 2022). When pitchers are not capable of certain movements (due to lack of ROM, strength, etc.), different pitch design techniques can be used. These include many different cues or adjustments such as leveraging seams at different angles for seam shifted wake effects (Smith et al., 2021). Widening the middle and index finger reduces the spin rate of the pitch, causing drop in the depth of the pitch and reduced speed similar to the action of a change-up, without requiring the pitcher to pronate their forearm. However, the widened grip stretches the flexor digitorum superficialis and flexor digitorum profundus and may also increase the stress placed onto the pitcher's forearm. Spin rate arises from friction, and achieving the desired movement profile involves manipulating the shear force applied to the ball upon release. This manipulation is likely influenced by factors such as the chosen grip, seam, and wrist orientation from coaching cue adjustments, as well as physiologic elements such as anthropometric and anatomical capabilities.

2.4 Biomechanics

The individual biomechanics of pitchers play a significant role in movement efficiency, joint loading and performance. The pitching motion entails numerous coordinated actions that could contribute to pronation/supination bias. For instance, a 10° increase in forearm pronation at foot plant leads to a 5° decrease in elbow flexion (Manzi et al., 2023). Pitchers with a supination bias (or biceps dominant) have smaller arm actions and greater forearm flexion at SFC, whereas those with a pronation bias (or triceps dominant) tendency demonstrate longer arm actions, increased elbow extension, and greater engagement of the triceps during follow-through. Biomechanical factors can also significantly impact joint loading. For example, a 10° increase in supination results in a 0.8 Nm increase in elbow varus torque and a 4.1 N increase in proximal elbow medial torque (Yanai et al., 2023). It is unclear if the individual preference in the degree of forearm pronation is acquired over time due to the throwing motion, inherent, or influenced by strength, but is independent of playing level (Manzi et al., 2023).

2.4.1 Max Voluntary Isometric Varus Strength & Biomechanical Efficiency

Maximum voluntary isometric varus strength determines how much varus strength can be produced by the elbow musculature of the pitcher that has been measured using a new technique involving the Biodex isokinetic device. The percentage of maximum voluntary isometric varus strength determines the effort required to unload and avoid the estimated joint failure for shielding the UCL based on the varus torque from pitching (Yanai et al., 2023). This provides in-vivo knowledge and assessment of the pitchers' strength in supporting the UCL as well as the biomechanics and torque produced from pitching. It has been shown that playing level, as well as taller and heavier bodies have greater biomechanical efficiency along with different kinematic variables (Crotin et al., 2022). Both maximum voluntary isometric varus strength and biomechanical efficiency could be important for athlete monitoring and injury reduction, as performance specialists will understand how to raise biomechanical efficiency through coaching approaches that lower the relative torque to pitching velocity ratio. Similarly, a focused conditioning program should be established and adapted to advance medial elbow stabilization to shield the UCL from valgus tensile overload.

2.4.2 Fatigue and Biomechanical Compensation

Biomechanical compensations occur to maintain pitching performance, but can also impact joint stability, increasing the likelihood of injury (Birfer et al., 2019; Crotin et al, 2022).

To protect the throwing arm from altered movement patterns, assessing maximum voluntary isometric varus strength provides insights into pitchers' ability to withstand stress, which is crucial in understanding how fatigue and compensatory mechanisms may impact an individual and cause injuries. Biomechanical efficiency also is susceptible to fatigue caused by mismatched workloads and recovery schedules, such as having elevated pitch counts with limited rest periods for relievers. Thus, neuromuscular fatigue, ROM changes, or biomechanical compensation can create kinetic chain alterations, increase stress, and causing soft tissue adaptations that could increase the risk of injury (Birfer et al., 2019; Crotin et al., 2021). Manipulating stride length has been shown to alter fatigue levels. Research has shown that a reduced stride length caused a significantly decreased handheld grip dynamometer forearm strength post-pitching in comparison to their baseline strength before pitching (Crotin et al., 2021). Pitchers with greater valgus torque displayed less post-game middle finger (flexor digitorum superficialis) and ring finger (flexor carpi ulnaris) flexion strength than their pre-pitching values and did not fully recover the day after (McHugh et al., 2023). The low valgus torque pitching group displayed no finger flexion 'pinch' strength loss post-game or the day after. This infers that pitchers who throw at higher velocities, encouraging greater elbow varus torque, require a stringent strength monitoring process.

The difference in finger flexion strength loss displays the significance of biomechanical efficiency and forearm strengthening programs, especially for pitchers enduring greater medial elbow stress. Pitchers are often cued to throw breaking balls with increased middle or index finger pressure. This will increase recruitment of the FPM and the rate of fatigue while reducing force production and can negatively impact pitching kinematics and performance metrics, such as velocity and strike percentage (Nara et al., 2023).

CHAPTER 3
METHODS

3.1 Participants

Twenty-two Division I college baseball players (16 right-handed and 6 left-handed; age 20.4 ± 1.4 years, height 1.85 ± 0.07 m; body mass 95.5 ± 11.3 kg) participated in this study after providing written informed consent approved by the Louisiana Tech University Institutional Review Board. All pitchers were considered healthy with no significant injury and had fully recovered from any previous injury at the time of testing. Testing occurred in the Sport and Movement Science Laboratory and J. C. Love Field at Pat Patterson Park at Louisiana Tech University.

3.1.1 Exclusionary Criteria

Pitchers who were not deemed healthy or lacking medical clearance were excluded from participation in this study. Additionally, pitchers who utilized a splitter variation were excluded from the assessment of change-up spin direction deviation.

3.2 Experimental Design

3.2.1 Physical Traits

The experiment began at the start of the fall quarter (offseason), before team baseball practices. All athletes underwent a standardized dynamic warm-up session, followed by a 5-minute session on the upper body ergometer (Monark, Varberg, Sweden) set at 50 rpm and 50 W similar to previous research (Newsham et al., 1998). The physical testing was designed to examine the isokinetic forearm pronation and supination strength of NCAA Division I collegiate baseball pitchers using the Biodex Isokinetic Dynamometer (Biodex, Inc., Shirley NY) adhering to the manufacturer's protocol (Biodex Medical Systems) (Figure 2). The Biodex measures forearm pronation and supination concentric strength by assessing the torque generated as the participant rotates their forearm. During the test, the athlete's trunk was secured with straps across the chest and waist, and additional setup information was noted for consistent positioning in future tests. As the participant supinates and pronates their forearm, the dynamometer records the force exerted at various angular velocities for five repetitions at angular velocities of 120, 180, and $240°\cdot s^{-1}$. Testing was completed in the pitcher's measured full ROM in forearm pronation and supination. Four warm-up repetitions were completed before the test at each speed at 25, 50, 75, and 100% of the pitcher's perceived maximal effort. Verbal encouragement was given to the athletes during each test to enhance motivation, and a 2-minute interval was given after testing at each speed for recovery.

Figure 2. The seated Biodex isokinetic dynamometer forearm pronation (left) and supination (right) test.

The hand-held pencil method was used to measure forearm pronation and supination ROM (Karagiannopoulos et al. 2003). Participants were seated, elbow at 90°, arm adducted to their side. The forearm was placed in a neutral position, with the palm facing inwards and a pencil was held in a fist of the participant's hand, parallel to the forearm. To assess pronation, participants were instructed to rotate their forearm so that the palm faced downward. After returning the forearm to the neutral position, participants were instructed to rotate their forearm so that the palm faced upward into supination. Maximal pronation and supination were measured by the tester with a handheld goniometer axis aligned with the participant's head of the third metacarpal, the stationary arm perpendicular to the floor, and the active arm parallel to the pencil. The assessment was completed on both their dominant (throwing) and non-dominant sides. This method has been determined to be a statistically valid and reliable form of measurement and 5° is accepted as an instrument error (Karagiannopoulos et al. 2003).

The Jamar hand dynamometer (Sammons Preston, Bolingbrook IL) was used to assess grip strength (Figure 3-1). Participants were seated in an armless chair, shoulder adducted forearm neutral and elbow flexed at 90°. Participants followed the protocol of Mathiowetz et al. (1984). The best of 3 trials was recorded for the pitcher's dominant hand. The device was calibrated pre- and post-testing. The ArmCare.com dynamometer device (Crossover Symmetry LLC, Indialantic, FL, USA) (Figure 3-2) and B&L Engineering device (B&L Engineering, Santa Ana, CA) (Figure 3-3) were used to assess the pinch strength of the flexor digitorum superficialis and flexor carpi ulnaris (Figure 3). Participants were in a contralateral half-kneeling position with their shoulder adducted, elbow flexed to 90°, and knees and feet aligned with the hips. They gripped the device with their fastball grip, having the index and middle finger above and thumb underneath the device without flexing or extending the wrist. Two trials were conducted to measure maximum isometric strength. A third trial was completed if one is greater than 10 percent of the coefficient of variation. Each trial has a 10-second recovery period between trials.

Figure 3-1. The grip strength test assesses the crush strength of the forearm muscles using the Jamar grip dynamometer.

Figure 3-2. The pinch strength test assesses the strength of the flexor digitorum superficialis and flexor carpi ulnaris using the ArmCare dynamometer.

Figure 3-3. The pinch strength test also assesses the strength of the flexor digitorum superficialis and flexor carpi ulnaris using the B&L Engineering dynamometer.

3.2.2 Anthropometric Assessments

All pitchers' hands were photocopied and stored for anthropometric measurement. The key measures include middle finger length, index finger length, thumb length, index to middle finger length discrepancy, and palm height. Pen marks were placed at the center of the distal fingertips and the metacarpophalangeal joint (knuckle) for the thumb, index, and middle fingers. A standard tape measure was used to measure the distance of the thumb, index, and middle fingers between these landmarks to the closest cm. Index to middle finger discrepancy was taken as the difference in middle finger length subtracted by the index finger length. Palm height was calculated as the middle finger length subtracted from the hand length.

3.2.3 Ball Flight

Ball flight metrics were collected by a Rapsodo 3.0 device (Rapsodo, Chesterfield, MO) for every pitch thrown in the six weeks of fall 2023 intrasquad scrimmages. The metrics collected for this study included breaking ball spin rates, breaking ball velocity, fastball spin efficiency, fastball velocity and fastball spin direction, and change-up spin direction. Spin velocity ratio was calculated from pitch velocity (mph) divided by spin rate (rpm), and change-up spin direction deviation was the change-up spin direction subtracted by fastball spin direction.

Numerous ball flight metrics are utilized to assess pitches and for this study, three specific measurements were chosen for their relevance to forearm positioning and success in throwing different pitch types. First, spin efficiency was chosen for the pitchers' preference in forearm positioning in throwing the greatest velocity with their fastball. Second, the breaking ball spin rate was chosen to determine the pitchers' ability to apply force and maintain supination in spinning the baseball. For the evaluation of breaking pitches, spin rate, not pitch velocity, vertical or horizontal movement was included because it is dependent on the type of pitch and specific objectives of the pitcher. Third, change-up spin direction deviation was chosen for evaluating a pitcher's proficiency in throwing a true pronation change-up. This evaluation excluded pitches of splitters and split change variations, ensuring an examination focused on pronation ability, as these change-up alternatives involve distinct grip techniques that reduce spin and affect movement and velocity differently.

3.3 Statistical Analysis

Statistical analysis was conducted using RStudio software (version 2023-12-17, Boston, MA 02210). Pearson's correlation coefficient was employed to assess the relationships between variables, while multiple regression analysis was utilized to understand the relationship between variables. All statistical tests were conducted at a significance level of 0.05.

CHAPTER 4

RESULTS

4.1 Pearson's Correlation

Pearson's correlation tests were conducted to analyze the relationship between forearm rotation strength biases and specific ball flight metrics. Pronation strength had a significant positive correlation with fastball spin efficiency ($r = 0.408$, $p = 0.05$). The Supination/Pronation Strength Ratio, displayed a moderate negative correlation with decreased spin efficiency on their fastball ($r = -0.429$, $p = 0.05$) and significant negative correlation with decreased change-up spin direction deviation ($r = -0.454$, $p = 0.05$). However, weak correlations were observed between Supination/Pronation Strength Ratio and breaking ball spin rate (Table 1). There was a statistically significant positive correlation between FB spin efficiency and pinch strength on the B&L Engineering device ($r = 0.462$, $p = 0.04$) and with the ArmCare pinch strength ($r = 0.467$, $p = 0.03$) (Table 1). An examination of anthropometric factors demonstrated a statistically significant negative moderate correlation between decreased change-up SDD and pitchers with greater middle/index finger discrepancy ($r = -0.531$, $p = 0.03$), and longer middle fingers ($r = -0.502$, $p = 0.05$). However, all other independent variables, including index, and thumb length, middle/index finger discrepancy, and palm height demonstrated weak correlation with the other ball flight metrics (Table 1). The correlations between forearm ROM measurements in supination/pronation and ball flight metrics were not significant.

(Table 1). Fastball velocity displayed a surprisingly significant positive correlation with the Supination/Pronation Strength Ratio (r = 0.516, *p* = 0.01) and negative correlation to pronation strength (*r* = 0.431, *p* = 0.05). The findings highlight the complexity of physiological and anthropometric factors in the forearm and the crucial role of biomechanics in both ball flight and performance.

Table 1. Correlation matrix displaying Pearson's correlation coefficients (*r*) and *p*-values between independent variables including forearm strength, ROM, anthropometrics, grip strength, pinch strength and dependent variables of ball flight metrics.

	FB Spin Efficiency	CH Spin Direction Deviation	BB Spin Rate	FB Velocity	Mean ± S.D.
Sup/Pro Strength Ratio†	-0.429* (0.046)	-0.454 (0.078)	0.264 (0.235)	0.516* (0.014)	0.781 ± 0.17
Supination Strength (ft/lb)	-0.110 (0.626)	-0.360 (0.170)	0.053 (0.813)	0.244 (0.273)	7.76 ± 0.17
Pronation Strength (ft/lb)	0.408* (0.049)	0.260 (0.331)	-0.318 (0.150)	-0.431* (0.045)	10.14 ± 1.67
Forearm ROM Ratio†	0.055 (0.809)	0.061 (0.823)	-0.383 (0.079)	0.202 (0.366)	108.22 ± 13.06
Pronation ROM (°)	-0.201 (0.369)	-0.288 (0.280)	0.031 (0.890)	0.138 (0.539)	84.18 ± 11.25
Supination ROM (°)	0.279 (0.208)	0.164 (0.545)	-0.315 (0.154)	-0.010 (0.963)	91.05 ± 11.75
Grip Strength (kg)	0.209 (0.351)	-0.057 (0.834)	-0.292 (0.188)	0.204 (0.363)	65.82 ± 9.68
B&L Engineering Pinch Strength (kg)	0.462 (0.037)	-0.057 (0.834)	-0.272 (0.221)	0.224 (0.317)	11.86 ± 2.13
ArmCare Pinch Strength (lb)†	0.467 (0.032)	-0.368 (0.161)	0.087 (0.699)	0.159 (0.480)	48.44 ± 7.87
Extension Strength (ft/lb)	0.329 (0.134)	-0.110 (0.685)	-0.034 (0.880)	0.240 (0.283)	7.46 ± 2.07
Flexion Strength (ft/lb)	0.197 (0.379)	-0.077 (0.778)	-0.459 (0.049)	-0.097 (0.668)	17.79 ± 3.85

Middle Finger Length (cm)	-0.032 (0.888)	-0.502* (0.047)	-0.071 (0.754)	0.367 (0.093)	84.09 ± 4.34
Index Finger Length (cm)	-0.013 (0.954)	-0.170 (0.530)	-0.090 (0.691)	0.266 (0.231)	75.00 ± 3.55
Thumb Length (cm)	0.047 (0.835)	-0.111 (0.682)	-0.181 (0.421)	0.419 (0.052)	138.09 ± 6.23
Palm Height (cm)	0.091 (0.688)	-0.018 (0.948)	-0.183 (0.416)	0.288 (0.194)	109.09 ± 6.55
Discrepancy Length (cm)	-0.032 (0.888)	-0.531* (0.034)	0.004 (0.986)	0.224 (0.315)	9.09 ± 2.89

* $.01 \leq p < .05$
The sample size is 22 pitchers.
β (95% CI) = 95% confidence interval for beta; FB = Fastball; CH = Change-up; SDD = Spin Deviation Direction; BB = Breaking Ball.
† Indicates multicollinearity of variable, so it is not included in the overall prediction models. The order of variables shown is the order these variables were entered into each prediction model.

4.2 Multiple Regression Analysis

Multiple regression analyses were performed to explore the predictive relationships between isokinetic forearm strength, grip strength, finger length, and ball flight metrics. Three regression equations were developed to predict fastball spin efficiency, change-up spin direction deviation, and breaking ball spin rate. These equations were created through backwards elimination to identify the variables with the most substantial effects. The B&L Engineering device was used as the measure of pinch strength as it was completed in one session during the same testing period as the other strength variables.

4.2.1 Fastball Spin Efficiency Prediction

The first regression model aimed to predict fastball spin efficiency. The predictors included isokinetic supination strength, isokinetic pronation strength, and pinch strength. This model demonstrated statistical significance in predicting fastball spin efficiency (Adjusted R-squared = 0.399, F(3, 18) = 5.471, p = 0.008). Ioskinetic pronation strength (β = 1.96, p = 0.008) and pinch strength (β = 1.65, p = 0.008) showed significant positive effects on fastball spin efficiency, while isokinetic supination strength exhibited a significant negative effect (β = -1.93, p = 0.022) (Table 2).

Table 2. Multiple regression equation showing β coefficients (95% CI) and p-values examining the relationships between fastball spin efficiency and predictor variables of isokinetic supination strength, isokinetic pronation strength, and pinch strength.

	β **(95% CI)**	p
Supination Strength	-1.935	0.022*
Pronation Strength	1.957	0.008**
Pinch Strength	1.647	0.008**

* .01 ≤ p < .05, ** .001 ≤ p < .01, *** p < .001
The sample size is 22 pitchers.

4.2.2 Change-up Spin Direction Deviation Prediction

The second regression model aimed to predict change-up spin direction deviation. The predictors included isokinetic pronation strength and middle finger length. This model was statistically significant in predicting change-up spin direction deviation (Adjusted R-squared = 0.374, F(2, 13) = 5.488, p = 0.019). Ioskinetic pronation strength demonstrated a significant positive effect (β = 5.450, p = 0.045), while middle finger length exhibited a significant negative effect (β = -3.057, p = 0.009) on change-up spin direction deviation (Table 3).

Table 3. Multiple regression equation showing β coefficients (95% CI) and *p*-values examining the relationships between change-up spin direction deviation and predictor variables of isokinetic pronation strength and middle finger length.

	β (95% CI)	p
Pronation Strength	5.450	0.045*
Middle Finger Length	-3.057	0.009**

* $.01 \leq p < .05$, ** $.001 \leq p < .01$, *** $p < .001$
The sample size is 22 pitchers.

4.2.3 Breaking Ball Spin Rate Prediction

The third regression model aimed to predict breaking ball spin rate. The predictors included pinch strength, forearm extension, and forearm flexion. The results revealed that the model significantly predicted breaking ball spin rate (Adjusted R-squared = 0.284, F(3, 18) = 3.783, $p = 0.029$). Forearm extension was a significantly positive predictor ($\beta = 53.45$, $p = 0.040$). Forearm flexion ($\beta = -35.74$, $p = 0.008$) was a significantly negative predictor. Pinch strength had a negative relationship ($\beta = -38.57$, $p = 0.054$) (Table 4).

Table 4. Multiple regression equation showing β coefficients (95% CI) and *p*-values examining the relationships between breaking ball spin rate and predictor variables of pinch strength, extension strength and flexion strength.

	β (95% CI)	p
Pinch Strength	-2.063	0.054
Extension Strength	2.219	0.040*
Flexion Strength	-2.995	0.008**

* $.01 \leq p < .05$, ** $.001 \leq p < .01$, *** $p < .001$
The sample size is 22 pitchers.

These findings suggest that while certain forearm isokinetic strength and anthropometric factors have predictive value for specific ball flight metrics, others may not play significant roles. Further research is warranted to determine the complex relationships between forearm biomechanics and ball flight metrics.

CHAPTER 5

DISCUSSION

The study's results confirm the significance of forearm supination and pronation physical traits and anthropometric biases in shaping pitch characteristics. Pitchers with distinct biases demonstrated unique spin metrics and pitch characteristics, highlighting the individualized nature of pitching mechanics. As expected, pitchers with reduced supination isokinetic strength, increased isokinetic pronation and pinch strength displayed greater spin efficiency on their fastball. Strengthening the flexor digitorum superficialis and flexor carpi ulnaris for 'pinch strength' may be important for staying behind the ball and improving fastball spin efficiency.

Contrary to the hypothesis, and despite the common belief amongst coaches and players of the importance of grip strength for spin rates, grip strength did not significantly influence the hypothesized metrics of spin. However, it was found that forearm flexion has a negative relationship and forearm extension is a significant predictor or increased breaking ball spin rate. Similarly, the association between forearm rotation ROM and ball flight metrics did not align with the ball flight hypotheses.

Anthropometric factors, such as middle finger length and index to middle finger discrepancy, emerged with an unexpected relationship to change-up movement. These findings suggest that coaches and sports performance staff could consider such factors in talent identification and player development strategies or 'pitch design' to determine when certain pitches or coaching cues may be appropriate for specific pitchers. Emerging techniques such as the ‘kick change’ (Figure 4) could be explored further to enhance change-up movement (Strom, 2024). This technique has pitchers curl or ‘spike’ their middle finger, applying more pressure and allowing the ball to release from the ring finger to achieve the desired movement. This aligns with the findings that shorter middle fingers and reduced middle to index finger discrepancies are correlated with increased change-up movement. This supports the notion that results must be personalized for each pitcher rather than generalized or ‘bucketed’ based on physical or anthropometric categories, to anticipate a specific relationship with performance. Similarly, ‘spiking’ the index finger can assist pitchers experiencing difficulty throwing a breaking ball by emphasizing a stiff wrist and increasing middle finger pressure in a position of reduced supination. However, the anthropometric measures from this study did not impact breaking ball spin rates or other dependent variables to support the hypotheses.

Figure 4. Example of the 'kick-change' grip (left) compared to a traditional change-up grip (right) (Strom, 2024).

5.1 Application

These results display the importance of taking a multidimensional approach to understanding how all these variables and pitching mechanics influence performance. Greater understanding and archetyping of pitchers' preferences will help to modify and individualize training to improve performance, potentially reduce injury risk, and determine the athletes in greatest need of intervention. The results of this study can be used for player development strategies, and help contribute to the understanding of biomechanical loading, relative risk, and workload management.

Although not assessed in this study, it is important to evaluate the throwing mechanics of a pitcher. This could help to determine if there are correlations between the pitcher’s anthropometric, and physical characteristics as well as ball flight metrics. Even when strengths are understood, programs may have to be individualized based on the inherent risks of a pitcher’s profile. Recognizing the compatibility of pitch types with pitchers' biomechanical preferences is essential for optimizing performance and potentially reducing injury risk. Pronation-dominant pitchers may encounter challenges in generating sufficient spin and velocity on breaking pitches, such as curveballs and sweeping sliders. Instead, they may find success with cutters and relying on effective fastballs and change-ups. They may benefit from supination exercises, and strengthening of the flexor carpi ulnaris for ulnar deviation. On the other hand, supination-dominant pitchers may have a broader repertoire of breaking ball shapes and prefer cutters or sinkers as their primary fastball. Pitchers with this strength bias could see advantages from utilizing two finger (middle and index) holds, or carries to strengthen the flexor digitorum superficialis and flexor carpi ulnaris muscles. As evidenced by this study, beyond their role in supporting the UCL, these two muscles play a key role in enhancing fastball spin efficiency and preserving pitchers ball flight metrics throughout a game.

In addition to optimizing pitch selection based on biomechanical preferences, attention to strength training and recovery is crucial. Pitchers with supination strength or favorable anthropometric qualities for producing effective breaking balls may find themselves relying more on these pitch types during games, leading to increased muscle fatigue and strain. As a result, they may require additional strengthening exercises, recovery protocols, or modified workloads to manage the added fatigue effectively. Pitchers fatigue at different rates, and assessment of their Stress Shielding Ratio, such as evaluating maximum voluntary isometric varus strength relative to elbow varus torque in pitching, or biomechanical efficiency, can provide information into understanding fatigue, compensatory mechanisms of injury, and appropriate assigned workloads to avoid movement adaptations that increase joint loads. The use of dynamometers or isokinetic devices are highly recommended for measuring forearm grip, pinch and rotation strength. Through integrating throwing arm specific strength testing, sport performance, sports medicine, and skill coaches can effectively monitor strength and fatigue that can potentially lessen injury risk.

This multidimensional approach that integrates anthropometric measurements, physical assessments, and biomechanical analysis, offers valuable insights to establish personalized training profiles tailored to pitchers' unique characteristics. By individualizing training strategies and optimizing pitch selection, coaches and pitchers can maximize performance while minimizing injury risk, ultimately helping each pitcher reach their full potential on the mound.

5.2 Limitations & Future Directions

First, the sample size of pitchers in this study was relatively small, consisting of only twenty-two Division I college baseball players. A larger sample size would allow for more robust statistical analysis and potentially uncover additional stronger associations and significant differences. Second, all pitchers included in the study played on the same team and were coached by the same coaching staff, including the principal investigator of this work. This homogeneity may have introduced bias and limited the generalizability of the findings to a broader population of baseball pitchers. Third, as a member of the coaching staff, the principal investigator has to focus on improving all pitchers' deficiencies in all areas despite their biases that may have introduced confounding influences affecting the results. Lastly, it is impossible to hold grip constant among pitchers and variations in seam orientation, finger pressure, and mechanics as well as coaching advisement by the principal investigator may have masked potential differences and performance decrements associated to forearm biomechanics.

Despite these limitations, this study lays the groundwork for future research in several key areas. Replicating the protocol with a larger and more diverse sample of baseball pitchers, encompassing players from various teams, levels of competition, and coaching backgrounds. This would help validate the generalizability of the observed relationships between forearm biomechanics and pitch characteristics. Additionally, longitudinal studies tracking pitchers' development over time could provide valuable insights into how forearm biomechanics evolve with training and experience. By monitoring changes in pitching mechanics and performance metrics, researchers could better understand the long-term implications of forearm biases on pitching success and along with lowered injury risk.

Investigations into individualized coaching strategies tailored to pitchers' unique biomechanical profiles could enhance player development and performance optimization. It is believed that these studies are being done by all professional baseball organizations, but would be useful to coaches at other levels of play to have this research be public. By identifying and capitalizing on each pitcher's strengths and preferences, coaches can maximize their potential while minimizing associated risk of injury. Overall, while this study offers important insights into the role of forearm in pitching, future research endeavors should address these limitations and explore new avenues for understanding and improving pitching performance.

CHAPTER 6

CONCLUSION

This study demonstrates the relationships between forearm pronation/supination ROM and strength biases, anthropometric factors, grip/pinch strength, and pitch characteristics among baseball pitchers. Assessment and training strategies tailored to pitchers' unique profiles are essential to maximizing individual development. This study focused on performance, yet a comprehensive understanding of these factors will not only enhance talent identification and player development, but also assist in establishing injury prevention efforts for baseball pitchers. Further research will be crucial to determine the impact of pitcher archetypes on joint loading. Practical applications and longitudinal effects of individualized training interventions to target specific biomechanical and anthropometric factors still need to be explored, as this may separate successful coaches/organizations from others who may lack a structured assessment and monitoring approach for their pitchers.

APPENDIX A
IRB APPROVAL LETTER

LOUISIANA TECH UNIVERSITY

Office of Research and Partnerships

MEMORANDUM

TO PI (s): Dr. David Szymanski, Dr. Mu Qiao

FROM: Dr. Walter Buboltz, Professor
buboltz@latech.edu

SUBJECT: **Human Use Committee - Review DECISION**

DATE: July 26, 2023

In order to facilitate your project, an EXPEDITED REVIEW has been completed for your proposed study:

HUC No.: **IRB 20-006 (renewal)**

TITLE: **Physiological and Anthropometric Characteristics of Div 1 Collegiate Baseball Players over an entire Year**

HUC DECISION: **APPROVED**

The proposed study's procedures were found to provide reasonable and adequate safeguards against possible risks involving human subjects. The information to be collected may be personal in nature or implication. Therefore, diligent care needs to be taken to protect the privacy of the participants and to assure that the data are kept confidential. Informed consent is a critical part of the research process. The subjects must be informed that their participation is voluntary. It is important that consent materials be presented in a language understandable to every participant. If you have participants in your study whose first language is not English, be sure that informed consent materials are adequately explained or translated. Since your reviewed project appears to do no damage to the participants, the Human Use Committee grants approval of the involvement of human subjects as outlined. Projects should be renewed annually. ***This approval was finalized on July 26, 2023 and this project will need to receive a continuation review by the IRB if the project continues beyond July 26, 2024*** **ANY CHANGES** to your protocol procedures, including minor changes, should be reported immediately to the IRB for approval before implementation. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of Sponsored Projects.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Research and Partnerships or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

Thank you for submitting your Human Use Proposal to Louisiana Tech's Institutional Review Board.

APPENDIX B
HUMAN SUBJECTS CONSENT FORM

HUMAN SUBJECTS CONSENT FORM

The following is a brief summary of the project in which you are asked to participate. Please read this information before signing the statement below. You must be of legal age or must be co-signed by parent or guardian to participate in this study.

TITLE OF PROJECT: Physiological and anthropometric characteristics of Division I college baseball players over an entire year

PURPOSE OF STUDY/PROJECT: Recently, there have been some studies which have investigated the physiological and anthropometric characteristics of basketball and rugby athletes. Studies of the physiological and anthropometric characteristics of baseball players are uncommon. To date, there has been only one study that has characterized these variables throughout an entire competitive baseball season. Therefore, the purpose of this study is to assess the physiological and anthropometric characteristics of Division I college baseball players over an entire year and to determine any relationships to offensive and defensive performance.

SUBJECTS: Because you are a Louisiana Tech men's baseball player, you are being invited to participate in this study. If you choose to participate and give your informed consent, you will be asked to test 4 times. Testing sessions will occur in September (off-season), December (preseason), March (midseason), and May (end-season).

PROCEDURE: During the initial session (team's first meeting), the research study will be verbally explained by the Project Director to you and you will answer a modified Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) to assess your general health. If you progress through this initial PAR-Q+ screening and are approved to participate in athletics from the LaTech Medical and Athletic Training Staff, you will complete a Descriptive Data Questionnaire which will allow you to list your age and describe your baseball playing and exercising experiences.

In September (off-season), you will meet in Scotty Robertson Memorial Gym to be assessed over two weeks. Three testing stations during weeks 1 and 2 of the off-season (September) as well as 2 weeks during the preseason (December), midseason (March), and end-season (May) will occur in the Applied Physiology Lab (APL), Memorial Gym basketball court, Sport & Movement Science Lab, and JC Love Field. Absolute strength testing (1RM back squat, bench press, and 1-arm landmine row) will occur in the Memorial Gym Strength Lab & Weight Room after week 2 and week 14.

The procedures for testing will be verbally explained by the Project Director to you before testing begins in September 2022. A total testing time for players completed, you will be assigned to one of three groups and rotate to the various stations on a given day until all are completed.

During week 1 in the APL, you will have height, body mass, body composition, hydration status, arm girths and finger and arm lengths, pinch and grip strength, and leg-low back strength measured. If you are a pitcher, you will complete the 1.5 mile-run test at the LaTech track, which will estimate your VO_2max. If you are a position player, you will sprint from home to first base after swinging at and bunting a baseball. Bat velocity will be recorded with a Blast motion sensor while batted-ball exit velocity will be measured with a Pocket Radar device. In Scotty Robertson Memorial Gym you will complete an overhead medicine ball throw, medicine ball hitter's throw, the 5-10-5 Pro agility test, and a baseball specific agility test. In the Sport & Movement Science Lab, you will perform 2-leg and 1-leg vertical jump tests from force plates while using a jumping (Vertec) device. You will also perform a 2-leg Myotest vertical jump test, 2-leg standing long jump test for distance and to estimate peak power, and 1-leg lateral to medial jump for distance.

During week 2 in the APL, pitchers will perform three different isokinetic tests to assess your throwing and non-throwing shoulder force production on the Biodex isokinetic device. The first test will be the shoulder internal and external rotation at 90º. The second test will be shoulder internal and external rotation at a modified 0º. The third test will be the shoulder diagonal 2 pattern flexion and extension. You will perform three different isokinetic tests to assess throwing and non-throwing lower arm force production on the Biodex isokinetic device. The first test will be the wrist flexion and extension. The second test will be forearm pronation and supination. The third test will be elbow flexion and extension. All of these tests measure force output at a specific speed (degrees per second) and range of motion. Also, in the APL, pitchers will perform a treadmill VO_2max test which measures the maximal amount of oxygen utilized by the body while running to failure well as perform the ArmCare range of motion (shoulder internal & external rotation and flexion) and strength (shoulder internal & external rotation, shoulder scaption, and grip) tests. In the Sport & Movement Science Lab, pitchers will throw from a custom-made pitcher's mound that is 60'6" from home plate. The mound will have two Bertec force plates embedded in it. Ground reaction forces, peak power, and other variables will be recorded. A 12-camera motion capture analysis system will be used to record your throwing mechanics while pitching from a custom-made pitching mound with two force plates. A Rapsodo device will be used to measure throwing velocity, spin rate, spin efficiency, pitch break, spin axis, and release point. Pitchers will wear a CosMed K5 portable metabolic unit while pitching to record oxygen consumption.

At the end of week 2, all players will be assessed for absolute strength in the Memorial Gym Strength Lab & Weight Room. Players will complete a one repetition maximum (1RM) in the back squat with three spotters while using a Z-Squat to measure foot placement and parallel squat depth to assess lower body strength. Players will complete a 1RM bench press test with three spotters to assess upper body pushing strength. Players will complete a 1RM one-arm landmine row test to assess upper body pulling strength. A certified strength and conditioning specialist (Project Director & Director of Baseball Performance) will evaluate all strength tests and spotting by players.

You will be re-assessed using the same tests, equipment, and procedures described above during the preseason (December), midseason (March), and end-season (May).

BENEFITS/COMPENSATION: At the end of this study, you will receive a Baseball Player Profile Report, which will include information about your physical fitness level and baseball performance skills. Also, you will learn how team health and skill performance data relates to offensive and defensive baseball performance. No compensation will be provided; however, you will receive a copy of the abstract upon request after the project.

RISKS, DISCOMFORTS, ALTERNATIVE TREATMENTS: You understand that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research. However, since you are a university athlete, you will have access to the medical and athletic training staff if an injury occurs. All tests and baseball-specific activities involved in this study present minimal risks to you, and are very similar to what you would normally experience during college baseball team practices/games. You might experience soreness. Muscle/tendon strains or soreness and ligament sprains due to near-maximal effort bat swings, pitching/throwing, and performance activities may occur. Since these protocols are typical of the daily activities during practice or games, there is little risk. Risk of injury will also be significantly reduced due to the warm-up before testing, close adult supervision, proper instruction, and a well-designed study. A very similar study to this one was conducted with the 2009 LaTech Baseball team without any injuries to the players by the same Project Director. You will be screened for health and medical risks. Specifically, you will be asked if you have had a muscle/tendon strain or ligament sprain before. If you have had an injury within the last month, you will not be able to participate. You will be considered free from injury in the lower and upper extremities if you make it through the LaTech Athletic Training/Medical Staff and PAR-Q+ health and medical screenings.

The risks associated with an exercise treadmill (VO_2max) test, such as fatigue, muscle soreness, irregular heartbeat, chest pain, and sudden heart attack, are about the same as those that may happen during strenuous athletic events. Severe irregular heartbeat, heart attacks, stroke, or death are extremely rare in adults with a normal, low-risk health history. To minimize these risks, you will be screened by the LaTech Athletic Training and Medical Staff as well as the PAR-Q+ health and medical questionnaire. Furthermore, a trained exercise physiologist (Project Director) will perform this procedure. This test is routinely performed in the APL with Kinesiology students in exercise prescription classes without any complications. Also, you will have your heart rate and rating of perceived exertion monitored continuously throughout the test. The test will be discontinued if any abnormal heart rate or rhythm is detected. Emergency equipment (Automated External Defibrillator) in the APL and trained personnel are available to deal with unusual situations which may arise.

The participant understands that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research.

The following disclosure applies to all participants using online survey tools: This server may collect information and your IP address indirectly and automatically via "cookies."

I,______________________________________, attest with my signature that I have read and understood the following description of the study, "Physiological and anthropometric characteristics of Division I college baseball players over an entire year", and its purposes and methods. I understand that my (Or my Child's) participation in this research is strictly voluntary and my (or my child's) participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University, the Baseball team, or my grades in any way. Further, I understand that I may withdraw (my child) at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results of the material will be confidential, accessible only to the principal investigators, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

Signature of Participant ____
Date _______________

CONTACT INFORMATION: The principal experimenters listed below may be reached to answer questions about the research, subjects' rights, or related matters.

PRINCIPAL INVESTIGATOR: David J. Szymanski, dszyman@latech.edu, 318-257-4432

CO-INVESTIGATOR: Mu Qiao, mqiao@latech.edu, 318-257-5467

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters:

Human Use Committee Chair:
Dr. Walter Buboltz, Professor, Director, of Training Counseling Psychology
Ph: (318) 257-4039, Email:

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