

HIP FLEXIBILITY ASSOCIATED WITH PITCHING TECHNICAL ERRORS

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ABSTRACT

Catherine Miller: Hip Flexibility Associated with Pitching Technical Errors
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Pitching technical errors have been linked to increased upper extremity injurious forces in baseball pitchers. Hip flexibility plays a key role in dynamic movement and may affect the ability of a pitcher to properly distribute force throughout a pitch. This could lead to certain technical errors and predispose a pitcher to injury. The purpose of this study was to determine if hip extension, internal rotation and external rotation range of motion is associated with baseball pitching technical errors in adolescent baseball pitchers. Each participant had their hip range of motion measured then pitched 15 fastballs while being filmed from the frontal and sagittal views. The videos were graded for technical errors. Point biserial Pearson r correlations were run between stance leg extension, bilateral hip internal rotation, bilateral hip external rotation and each technical error. No significant correlations were found. While it is still believed that hip flexibility plays a role in force transfer throughout the pitching sequence, this study did not support passive hip range of motion being correlated with technical errors. However, the majority of adolescent males did have restricted hip range of motion values compared to normative values. Active hip range of motion may be a more suitable measurement to use given the dynamic nature of baseball of pitching.

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LIST OF ABBREVIATIONS

BL_SFC	Backward lean at stride foot contact
BR	Ball release
FT_BR	Inadequate forward trunk tilt
LL_MER	Lateral trunk lean at maximal shoulder external rotation
LL_SFC	Lateral trunk lean at stride foot contact
MER	Maximal shoulder external rotation
OS_SFC	Open shoulder
SFC	Stride foot contact

CHAPTER I: INTRODUCTION

Baseball is one of the most popular youth sports in the United States.¹ There are nearly 20 million players in organized baseball leagues, with the majority being youth or adolescents.^{2,3} Injury rates in youth pitchers have recently increased due to modifiable risk factors including: pitching mechanics, pitching volume and frequency, muscular imbalances, muscular weaknesses and lower extremity inflexibility.^{4,5} Fortunately, these factors can be addressed from pre-participation examinations to attempt to prevent the risk of overuse injury in adolescents.⁶

Upper extremity overuse injuries are the most frequently occurring, costly pathology in baseball through all levels.^{1,7,8} Overuse injuries are primarily responsible for time loss from sport participation.^{1,8-11} The incidence of injury is heightened because of increased joint and soft tissue loading,¹²⁻¹⁴ that occurs when high stresses and repetitions are placed upon the elbow and shoulder during pitching.¹⁵⁻¹⁷ Overloading soft tissue structures leads to microtrauma that can eventually break down the stabilizing structures if not given adequate time to recover.^{7,15} Biomechanical pitching errors have been shown to exacerbate this stress placed upon the joints, increasing injury risk.^{7,16,18-20}

Pitching kinematic sequencing begins in the lower extremity at stride foot contact^{17,21,22} and transitions up the kinetic chain through the ankle, knee, hip, torso, shoulder, elbow and wrist before ball release from the hand.^{20,23-27} According to the summation of speed principle, to achieve optimum speed at a distal segment, the motion has to be initiated at a proximal segment and progress distally.²⁷ Joint movement begins when the preceding joint has achieved its greatest speed, creating a path for the forces to transfer via the kinetic chain.²⁷ Since a pitching sequence

is initialized with leg motion and terminated after the arm propels the ball towards the intended target,²¹ it is important to investigate the lower extremity when assessing pitching biomechanics.

The lower extremity is responsible for up to half of the gross force production during overhead throwing,²⁸ leading researchers to believe that the transfer of forces from the lower extremity through the trunk may have effects on upper extremity joint loading.^{7,27} Restricted range of motion at the hip joint has been shown to disrupt pelvic rotation sequencing preventing the smooth transfer of force from the lower extremity through the torso to the upper extremity.^{26,28} An alteration in hip external rotation, hip internal rotation and/or hip extension range of motion could predispose an athlete to improper pitching mechanics.²⁹ Many previous studies have focused on rotational range of motion,^{8,17,29-31} without studying extension. Hip extension is restricted by soft tissue structures that are involved with the rotational ability of the hip.³² The iliofemoral ligament, ischiofemoral ligament, pubofemoral ligament, rectus femoris muscle and iliopsoas muscle are all taut when the hip is actively or passively placed into extension.³² Tension within those ligaments and muscles subsequently create a greater resistance to hip rotation, a crucial component in overhead throwing.^{29,33,34}

If hip extension is restricted, athletes commonly present with an anteriorly tilted pelvis to maintain sufficient hip rotational range of motion during baseball pitching.³⁵ In the general asymptomatic population, anterior pelvic tilt occurs in about 85% of males and 75% of females.³⁶ This anterior tilt decreases the amount of stretch on the anterior capsuloligamentous and musculotendinous structures so the extra slack provided may be utilized to achieve adequate rotational range of motion.³⁶ Although hip flexion may allow for a greater rotational ability during sport,³⁷ it is a poor postural stance.^{32,35} Tightness at the hip may also influence stride length as well as lead foot placement at stride foot contact,³³ which are responsible for the timing

of the pitching sequence. Poor foot positioning at stride foot contact can lead to improper pelvic rotation, resulting in additional technical errors committed up the kinetic chain. Improper pelvic rotation has been shown to influence upper extremity kinetics.¹⁷ Over time, with repetitive pitching, it appears that changes in the lower extremity can lead to undesirable changes at the elbow and shoulder.

The five pitching technical errors that we examined in this study were open shoulder at stride foot contact, backwards trunk lean at stride foot contact, lateral trunk lean at stride foot contact, lateral trunk lean at maximal external rotation and inadequate forward trunk flexion at ball release. Faulty biomechanics such as these have been shown to predispose the shoulder and elbow joints to injurious loads.^{12,21-23,38-42} It is possible that faulty biomechanics are a result of lower extremity, specifically hip, flexibility. Ensuring adequate hip flexibility and, in turn, correct biomechanics has the potential to mitigate upper extremity injurious forces, leading to a decrease in injury rates,^{20,24} time loss and medical expenses.¹

The purpose of this study was to determine if hip extension, internal rotation and external rotation range of motion is associated with baseball pitching technical errors in adolescent baseball pitchers. The potential findings from this study may be able to aid in the creation of prevention programs that target modifiable injury risk factors. It will also place emphasis upon the importance of hip range of motion for movement sequences that involve both the lower and upper body. This focus may be carried into many other sports that involve the coordination of all extremities.

CHAPTER II: LITERATURE REVIEW

Injury in Baseball

Among all sports in the United States, baseball has one of the highest number of participants (over 20 million) with rapid growth shown throughout youth, collegiate and professional levels.^{3,6,43} Even though baseball is accepted as a generally safe sport,^{41,43,44} the prevalence of injury can have a substantial effect on time loss and finances due to the significant number of players.¹ Upper extremity injuries are the most commonly occurring injury in baseball. They are generally considered any type of pain at the elbow or shoulder that occurs while pitching or afterwards, as joint pain is a precursor to a more serious pathology.⁴¹

Injury Incidence

The upper extremity accounts for more than half of all injuries sustained in baseball,^{1,9,43} with over 42% from non-contact mechanisms such as throwing.⁴³ About 69% of pitchers have sustained shoulder injuries resulting in time loss.⁹ Major time loss is considered to be ≥ 10 days lost from participation, moderate time loss is considered to be 7-10 days lost from participation and minor time loss is considered to be < 7 days lost from participation.^{9,43} Major time loss occurs in about 25% of baseball injuries, with 10% of cases requiring surgery.⁴³ Studies on incidence of injury in youth and adolescents have been reported to vary. Radelet et al⁴⁵ found baseline injury rates per athlete exposure in youth sports during the 1999 and 2000 seasons to be 1.7 per 100 athlete exposures for all events.⁴⁵ Powell and Barber-Foss⁴⁶ reported high school injury rates to be 13.2 per 100 athlete exposures from a prospective study that involved over 2,000 participants.

Soft Tissue Pathology

Average ball velocities range from 34 to 39 m/s^{16,18,21,47} for adults and 31.1 to 34.8 m/s^{22,48} for youth. Pitching at these speeds generates excessive torques at the shoulder and elbow that often go beyond the elastic tensile strength of the soft tissue structures around the joints.^{18,49} Younger pitchers are more prone to these types of injuries due to skeletal immaturity,^{6,41} as growth plates reside at the epiphyseal plates, articular surfaces of the joints and musculotendinous junctions.⁴⁵ These areas are especially weak when allowing for bone growth during puberty.²³ Repetitive trauma sustained by the growing tissue between the ages of 5 and 17 can cause pain,⁴⁵ bony deformation and long term disability.^{6,41}

Internal impingement, rotator cuff irritation and SLAP lesions are common shoulder pathologies in adult pitchers.⁶ Internal impingement and rotator cuff irritation are exacerbated by scapular dyskinesis and the repetitive motion of pitching.⁴¹ As the humeral head elevates to the point of maximal external rotation, the rotator cuff can become irritated between the humerus and the glenoid rim. SLAP lesions occur with the shearing of the glenoid labrum during maximal external rotation and horizontal abduction of the shoulder. Adolescent pitchers commonly report anterior/superior shoulder pain due to proximal humeral epiphyseal, labral, rotator cuff or biceps tendon involvement.^{6,41} Ulnar collateral ligament injury, medial epicondylar apophysitis and osteochondritis dissecans are pathologies with the highest incidence in youth elbow pain.^{6,41} These injuries are most likely due to developing skeletal structures of youth and adolescents combined with the repetitive motion of pitching. Tensile stresses are placed on the medial elbow while compressive forces are placed on the lateral elbow during valgus extension overload.³² Medial tensile stress can lead to UCL injury, avulsion fractures and medial epicondylar apophysitis, or “Little League elbow”. Fractures or apophyseal injuries are more common in

younger athletes because the ligaments and tendons are stronger than the physes.⁵⁰ Lateral compressive stress can lead to osteochondritis dissecans at the radiocapitellar joint.^{32,50}

Pitching Mechanics

Baseball pitching is considered one of the most repeatable dynamic movements in sport.^{21,25} An early study by Pappas et al⁴⁷ claims there is little variability within pitchers, as they tend to be consistent in terms of mechanics and ball velocity. Stodden et al¹⁶ found inconsistencies within pitchers, reporting a significant association between throwing mechanics and increased ball velocity. Due to the dynamic nature of pitching, it is difficult to release a ball with great precision every time.⁵¹ The general path the baseball follows is called a “release arc”, in which the actual release of the ball from the pitcher’s hand occurs.⁵¹ Pitching is based on the pitcher being consistent in terms of ball release within the release arc. Multiple reports^{16,33,47,51} have suggested that to maximize ball velocity and minimize injurious forces, proper technique needs to be an early focus in the pitching cycle.^{16,33,47,51} The windup, early cocking/stride, late cocking, acceleration, deceleration and follow through are the six phases of pitching that will be discussed in this chapter shown in **Figure 1**.^{21,33,47,51}

Figure 1. The six phases of pitching

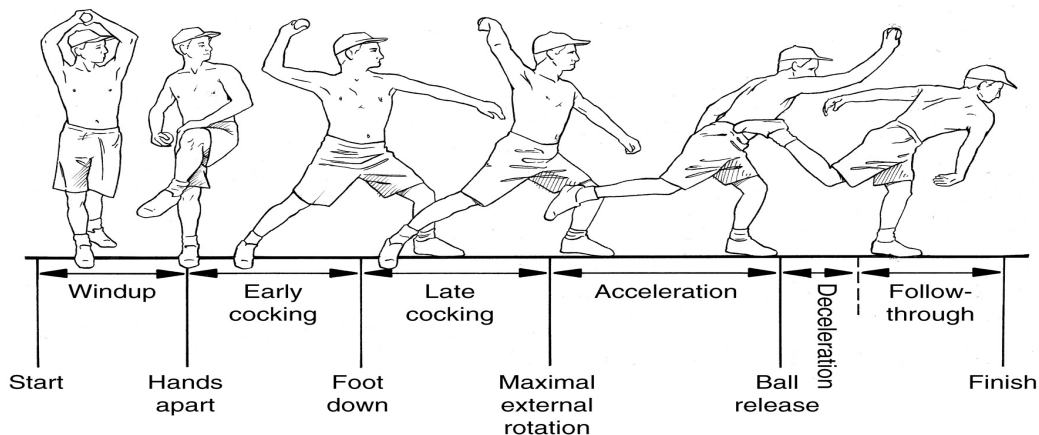


Table 1. Pitching Errors Overview

Point	Error	View
SFC	lateral trunk lean	sagittal
	open shoulder	frontal
	backwards trunk lean	frontal
MER	lateral trunk lean	frontal
	inadequate forward trunk flexion	
BR		sagittal

Windup

The windup phase begins with the first movement of the pitcher from the stance position towards the batter and ends with lead leg flexion while standing on the stance leg to provide a stable center of gravity (COG).²¹ At this point, shoulders are centered between home plate and 2nd base, hands are at the chest, and the ball starts to be removed from the glove. This phase occurs between 0.5-1.13 seconds^{47,51} and is responsible for the timing of the rest of the pitching sequence.³³ Flexing the lead leg too much can cause the shoulders to lean backwards, placing the spine in extension. Insufficient lead leg flexion can cause early trunk and pelvic rotation.⁵¹ Improper mechanics during the windup phase are noted if the pitcher has poor balance on the stance leg, initiates movement towards home plate prior to reaching a balance point and/or displays high hand placement by having a shoulder angle that exceeds ninety degrees of abduction.³³

Early Cocking/Stride

The early cocking/stride phase begins from the terminal stance of the windup and ends with stride foot contact (SFC). SFC is defined as the point at which the pitcher's lead foot makes initial contact with the ground, marking the beginning of the arm cocking phase. Before SFC occurs, the ball is removed from the glove and the throwing arm assumes a semi-cocked position. Poor hand positioning on the ball when it is taken out of the glove is considered another

mechanical fault. If the hand leaves the glove in a supinated position, the shoulder will reach maximal external rotation in the early cocking phase, instead of during the late cocking phase. This leads to “long-arming”,³³ or creating a lengthened path that the throwing arm has to travel to deliver the ball thus increasing the amount of torque to the elbow and shoulder joints.^{21,52} “Long-arming” can result from open foot position as well as supinated hand position.

Front foot positioning during initial ground contact should be in line with the back foot, facing home plate and directed slightly inward.^{21,33} If the stride foot is placed too far into internal rotation, it is considered to be a closed position and does not allow enough pelvic motion for sufficient transfer of energy up the kinetic chain. Open foot position occurs when the foot is placed too far in external rotation, leading to early pelvic motion. Both errors prevent the pelvis from rotating at an appropriate speed of between 400-700 deg/sec.⁴⁷ The placement of the stride foot at contact is an important component during pitching because it allows for proper energy transfer from the lower extremity to the upper extremity by increasing the time and distance the trunk has to rotate.³³ This more evenly distributes the amount of force sustained by the joints, decreasing joint loading and decreasing potential injury risk. Stride length also affects force transfer and is defined as the distance between the back foot and the front foot during the stride.³³ The distance should be about 85-100% of the pitcher’s height.^{21,33} Restrictions in hip range of motion can negatively affect stride length, which can diminish ball velocity and cause improper rotation or other technical errors.^{25,38} A small stride length decreases the amount of force generated by the lower extremity, lowering the trunk’s rotation potential. The pitcher will either have to increase upper extremity kinetics to compensate for the deficit to deliver the pitch of the same caliber³³ or he will be unable to deliver the ball at that velocity.⁴⁰

Open shoulder (OS_SFC) is an error that occurs at SFC if the pitcher prematurely squares his shoulders towards home plate, **Figure 2**.⁵¹ It can be caused by an early upper torso rotation,⁵³ inadequate stride length, open foot, diminished knee flexion at windup and/or rushing ball release.⁵¹ OS_SFC is observed when the anterior shoulder can be seen from the frontal plane, when only the lateral portion should be visible. If the athlete were to follow through with the pitch without making a correction, it would result in ball release towards the back of the release arc and a pitch that is delivered too high.⁵¹ Pitchers will compensate by lowering the elbow or “short arming” the pitch, decreasing the elbow to trunk flexion angle. Excess stress is placed upon the anterior shoulder and elbow, as the pitcher has to increase the horizontal adduction force in the throwing arm to counteract the excess horizontal abduction force.⁵³ Davis et al⁵³ and Aguinaldo et al⁷ have linked this error to higher injury forces such as increased elbow varus moments and increased shoulder internal rotation moments, respectively. In addition to stretching the anterior capsular and ligamentous tissue, the posterior capsule is shortened, increasing the risk of injuries such as internal impingement and labral tears.³²

Backward trunk lean (BL_SFC) is another error that occurs at SFC where the athlete’s trunk leans posteriorly, **Figure 3**. This is shown in the frontal view when the head is not aligned with the stride foot ankle. Proper form is demonstrated by vertical alignment of the head and torso over the lead foot ankle.^{13,54} Lateral trunk lean (LL_SFC) is an additional technical error involving the torso, but is seen in the sagittal view in **Figure 5**. LL_SFC is characterized by a posterior deviation of the pitcher’s head from a line drawn from the umbilicus vertically.^{13,54}

Late Cocking

The late cocking phase begins with SFC and ends with shoulder maximal external rotation (MER). After lead foot contact, the pelvis leads the trunk to rotate inward, extend and

move laterally toward home plate. A stable base is created on the lead leg as the knee begins to extend. At the same time, the cocked arm is flexed to 90 degrees at the elbow with the shoulder abducted 90-100 degrees, externally rotated to up to 185 degrees and horizontally adducted up to 20 degrees.^{33,55} At this point in the end of the phase the trunk, hips and legs are accelerating forward while the throwing arm remains cocked,²¹ moving posteriorly in relation to the head.⁵¹ Maximal external rotation (MER) is seen just prior to the arm accelerating in rapid internal rotation.

A lateral trunk lean at maximal external rotation (LL_MER) is the next error that will be quantified in this study, seen in the frontal plane in **Figure 4**. This error is present if the pitcher is unable to maintain torso and head positioning directly over the stride foot by leaning towards the non-throwing arm. Excessive lateral trunk tilt of more than a heads width from the vertical line is considered an error as it causes the upper torso and arm to accelerate towards the non-throwing shoulder.⁴⁸ This produces a deviation of the forearm from the pitcher's midline, which results in greater injury forces at the shoulder and elbow.⁵⁶⁻⁵⁸ If lateral trunk tilt is present it can lead to "long arming",⁵¹ defined previously and also shown to increase the valgus extension force at the elbow.^{21,33}

Acceleration

Arm acceleration is the shortest phase at 42-58 milliseconds.²¹ It begins at shoulder maximal external rotation and ends with the ball release from the hand.³³ It is considered to be among the fastest dynamic movement in sport.²¹ This phase is marked by elbow extension, shoulder internal rotation, wrist flexion, wrist pronation, trunk flexion and lead leg knee extension.⁵⁷ The humerus moves from maximal external rotation to internal rotation at over 9000 degrees⁵⁹ per second while the trunk moves into forward flexion, averaging 32 to 55 degrees.⁶⁰

The power during this phase comes from the previous phase and trail leg hip extension.⁶¹ It is transferred up the kinetic chain through pelvis rotation, trunk rotation and arm acceleration due to the summation of speed principle.²⁷ The final error that we will quantify in this study is inadequate forward trunk flexion (FT_BR) at ball release (BR), **Figure 6**. The midline of the trunk should be forward flexed to approximately 30 degrees upon BR.^{13,54} An increased trunk flexion angle has been shown to be associated with increased ball velocity.⁶⁰ If the pitcher does not display adequate forward flexion, he may then compensate with the upper extremity to ensure that the ball is delivered at the same velocity. The throwing arm will have to increase the force production to make up for the decrease in trunk angle, which can contribute to early fatigue and injury.²³ A summary of the technical errors that we looked at in this study are displayed in **Table 1**.

Deceleration

Arm deceleration begins with full elbow extension at ball release and terminates at shoulder maximal internal rotation. The shoulder is in maximal shoulder internal rotation of about 0 degrees²¹ and shoulder horizontal adduction of about 35 degrees.⁴² Upper extremity muscular activity is significantly decreased when compared to other phases, although the teres minor, infraspinatus and posterior deltoid are eccentrically activated to resist excessive humeral head movement. Escamilla and Andrews⁶² found that maximum rotator cuff activity is 37-84% MVIC, maximum serratus anterior activity is 69-106% MVIC, maximum trapezius activity is 51-78% MVIC, maximum rhomboids activity is 41-45% MVIC and maximum levator scapulae activity is 33-72% MVIC. At the end of arm deceleration, the pitcher is only standing on the lead leg while the trunk has rotated and flexed forward over the same leg.³³

Follow-Through

The final phase of pitching is the follow-through. This is marked by full extension of the stride leg, additional hip flexion, shoulder adduction, horizontal shoulder adduction, elbow flexion and forearm supination.²¹ During this time, the serratus and rhomboids act to stabilize the scapula.⁶³ The pitcher is then free to assume a fielding position to continue game play.

Injury Risk Factors

An elevated rate of pitching injuries has been recently noted due to a combination of extrinsic and intrinsic risk factors.^{5,45} Extrinsic factors include pitch frequency, pitch intensity and pitch volume.^{4,33,64} Intrinsic factors include pitching mechanics,^{18,20,47,60} UE and LE joint range of motion/flexibility,^{38,60,61} muscular strength^{23,38,64} and muscular control.^{33,41} Shanley and Thigpen⁶ describe extrinsic and intrinsic risk factors as modifiable or non-modifiable. The modifiable risk factors are pitching mechanics, pitch frequency, pitch volume, shoulder range of motion, lower extremity range of motion, muscular imbalance, and neuromuscular control. Non-modifiable risk factors are age, body mass index, height, coaching habits, and pitching performance satisfaction.^{4,5} For the purposes of this study, modifiable factors are of particular interest since they can typically be addressed noninvasively.

Pitch Count

Early sport specialization in the United States has led to the high prevalence of upper extremity pathology in youth, adolescent and high school populations.⁵³ Shoulder and elbow pain is reported in about half of 9 to 14 year old pitchers.⁶⁵ High pitch counts in combination with little recovery time subjects the shoulder and elbow to arm fatigue, which substantially increases the risk for pitching-related injuries. In 2013, the American Sports Medicine Institute (ASMI) provided pitch count recommendations specifically for youth baseball players. The six guidelines

include (1) at least 4 months out of the year with no competitive baseball pitching (2) adhering to pitch counts and recovery days (3) avoiding pitching on more than one team with seasons that overlap (4) avoiding playing both pitcher and catcher (5) participating in other sports, not just baseball (6) if shoulder or elbow pain is noted, discontinuing pitching participation.⁶⁶ Pitchers from 9 to 14 years of age are discouraged from throwing curveballs or sliders, as both pitch types have been shown to increase shoulder and elbow joint pain by over 50%. It is also advised to limit the same age group to 75 pitches per game and allow 1 day of rest for every 21 to 35 pitches thrown per week. It is recommended that adolescents from 15 to 18 years of age not exceed 105 pitches per day, allowing 1 day of rest for every 31 to 45 pitches thrown per week.⁴ In 2014, a cross-sectional survey study on U.S. youth baseball pitchers revealed that 45% of participants were involved in an organization that did not utilize pitching limits, 19% had pitched in multiple games within the same day in the past year, and 30.4% were playing for multiple teams without breaks in between seasons.⁶⁵ Youth baseball pitchers continue to be at an increased risk for joint pathology despite the public recommendations.^{4,53,66}

Faulty Pitching Mechanics

In addition to pitch counts and types, Lyman et al⁴ attributes the majority of shoulder and elbow pain in youth baseball pitchers to faulty mechanics. Fortenbaugh et al²³ adds that improper biomechanics, fatigue, pitch type and skeletal immaturity are all variables that increase loads on upper extremity joints. Errors such as open lead foot angle or open foot position at SFC, inadequate or excessive shoulder external rotation at SFC and excessive shoulder horizontal adduction during arm cocking have significant correlations to heightened upper extremity kinetics.¹⁸ A person's motion (velocity, joint angle, etc...) is termed a kinematic variable and the cause of a person's motion (torque, joint force, etc.) is termed a kinetic variable.¹⁸ For example,

shoulder kinetics is described as the trunk applying a force on the shoulder.¹⁸ Although this may benefit pitching performance by ultimately increasing velocity, greater kinetics can also be harmful.⁴⁸ To safely increase ball velocity, kinetic variables throughout the whole movement must also increase, starting first in the lower body then transferring the force to the upper body.²³ Otherwise, the throwing arm will be overloaded as force will then be produced by the upper extremity instead of the lower extremity, resulting in excess stress upon the elbow and shoulder.^{23,25} Experienced pitchers generally have a decreased risk of injury compared to youth and high school pitchers. It is theorized that this decreased risk can be attributed to better force transfer at the torso in the higher-level athletes.^{7,23,43}

Following rapid pelvic rotation, the trunk produces the rotational force that is transferred to the upper extremity as the shoulder goes into external rotation.^{67,68} The normal angle of shoulder external rotation ranges from 150 to 180 degrees.^{18,22,51} Oyama et al²² found that more than 40% of high school baseball pitchers demonstrate improper trunk rotation. The same participants also demonstrated later pelvic rotation velocity and greater maximal external rotation angles compared to pitchers who showed proper trunk rotation. In a study comparing pelvic rotation styles of baseball pitchers, it was shown that pelvic orientation at SFC has a strong positive correlation to the amount of external shoulder rotation.¹⁷ A strong negative correlation was shown between pelvic orientation at SFC and the amount of time it took from SFC to ball release. Interestingly, the group labeled as late rotators sustained significantly more forces at the shoulder and elbow during the cycle compared to early rotators.¹⁷ These results point to the importance of foot position at SFC to enable the athlete to optimize pitching performance by achieving proper pelvic rotation timing.

The Hip

The hip is supported by osseous, muscular, ligamentous and capsular structures.^{20,69} These allow for great stability but little mobility compared to other joints in the body, specifically the shoulder.³² Range of motion occurs in the frontal, sagittal and rotational planes⁶⁹ through flexion/extension, adduction/abduction, internal rotation/external rotation and circumduction.³² The relationship of the bony anatomy in each individual affects hip range of motion. The angle of torsion, angle of inclination, center edge angle and amount of acetabular anteversion are osseous factors that contribute to the amount of hip joint mobility.⁷⁰ These structural variations cause alterations in normal range of motion,⁷⁰ but are non-modifiable factors that cannot be definitively diagnosed without imaging. Among the modifiable factors are soft tissue constraints, shown in **Table 2**. Hip extension range of motion may be reduced with iliopsoas, tensor fascia latae, rectus femoris, capsular and ligamentous tightness.⁷¹ The primary ligaments of the hip are the iliofemoral, ischiofemoral and pubofemoral ligaments. They comprise the stabilizing capsule and are all taut in extension.^{32,69} In addition to soft tissue restrictions, muscular weaknesses of the gluteus maximus, semitendinosus and semimembranosus can contribute to decreased hip extension.³²

Hip Range of Motion

There are a few studies that look at normal hip range of motion in baseball players. Ellenbecker et al³¹ generated descriptive profiles of elite tennis players and professional baseball pitchers measuring prone hip internal rotation, hip external rotation and total rotation active range of motion. Compared with elite tennis players, baseball pitchers had significantly less total hip range of motion bilaterally. Of all of the participants that displayed greater than a 10 degree interlimb difference in hip rotation, 17% had differences with internal rotation and 42% had

differences with external rotation. From the results, it can be expected that noninjured baseball pitchers possess hip rotation range of motion symmetry. For the nondominant hip (lead leg), mean values for internal and external rotation were reported at 22 ± 8.9 and 34 ± 10.6 degrees, respectively. Mean values for internal and external rotation were reported at 23 ± 8.3 and 35 ± 9.1 degrees, respectively for the dominant hip (stance leg).

Table 2. Hip joint range of motion and tightened soft tissue structures³²

Hip Joint Motion	Taut Tissue
Flexion (knee in extension)	biceps femoris, semimembranosus, semitendinosus
Flexion (knee in flexion)	inferior capsule, posterior capsule, gluteus maximus
Extension (knee in extension)	iliofemoral, pubofemoral, ischiofemoral ligaments, psoas major
Extension (knee in flexion)	rectus femoris
Abduction	pubofemoral ligament, adductor magnus, adductor longus, adductor brevis
Adduction	ischiofemoral ligament, ITB, TFL, gluteus medius
Internal rotation	ischiofemoral ligament, gluteus maximus, piriformis, gemellus superior, obturator internus, gemellus inferior, obturator externus, quadratus
External rotation	iliofemoral, pubofemoral ligaments, TFL, gluteus minimus

A study by Laudner et al²⁵ measured bilateral prone rotational hip range of motion. They showed that on average, lead leg internal rotation at 27.7 ± 5.9 degrees and external rotation at 35.8 ± 3.4 degrees. Trail leg internal rotation was at 28.9 ± 7.2 degrees while external rotation was 35.4 ± 6.2 degrees. No statistically significant interlimb differences in hip rotational range of motion were found. A moderate relationship between lead leg total rotational range of motion and shoulder external rotation torque ($r=0.56$, $P=0.003$) was found. There was a significant relationship between total hip rotational range of motion of the trail leg and shoulder horizontal

adduction range of motion ($r=0.43$, $P=0.04$). Interestingly, trail leg external range of motion had a significant relationship to shoulder horizontal adduction ($r=-0.35$, $P=0.04$). These results indicate that more passive rotational hip range of motion is correlated with more passive shoulder motion.²⁵

Tippett⁶¹ measured active hip rotation range of motion as well as flexion and extension range of motion. Averages were reported as lead leg internal rotation at 34 ± 6.7 degrees and external rotation at 30 ± 3.7 degrees. Trail leg internal rotation was at 38 ± 6.7 degrees while external rotation was 30 ± 5.3 degrees. Active hip extension values for the lead and trail leg were 19 ± 3.9 degrees and 22 ± 4.5 degrees, respectively. Active hip flexion values for lead and trail leg were 123 ± 11.4 degrees and 119 ± 8.9 degrees, respectively. Hip extension of the trail leg was statistically significantly greater compared to the lead leg.⁶¹

Previous Studies

Limited research has been done involving hip range of motion as it relates to the upper extremity in baseball pitchers.^{8,29,30,34,72} Two studies found the association of lower extremity range of motion and glenohumeral range of motion in male collegiate pitchers.^{8,30} Analogue et al³⁰ found that higher scores on the sit-and-reach test for hip and trunk flexion had a strong correlation with total range of motion ($r=0.75$, $P\leq 0.01$) and external rotation ($r=0.75$, $P\leq 0.01$) of the throwing arm but did not have a correlation with external rotation of the non-throwing arm. Scher et al⁸ reported a significant relationship between lead leg hip extension and throwing arm shoulder external rotation in pitchers ($r=0.62$, $P=0.04$) and non-pitchers ($r=-0.64$, $P=0.02$) with history of shoulder injury. Another baseball study looking at hip rotation and its relationship to dominant shoulder torque and horizontal adduction, found that lead leg external range of motion had a significant negative relationship with horizontal shoulder adduction range of motion ($r=-$

0.36, P=0.04).²⁵ A significant relationship was also found between the total hip rotational range of motion and shoulder horizontal adduction range of motion (r=0.43, P=0.04).²⁹ Robb et al³⁴ found that the lead leg has increased passive range of motion in all hip measurements as compared to the trail leg. This similar study questioned whether passive hip rotation range of motion was related to pitching biomechanics.

Purpose

Of the studies involving hip motion and baseball pitching,^{8,17,25,28-31,34,38,61,72,73} two^{8,61} have included hip extension. Shown previously in **Table 2**, there are many soft tissues that limit hip joint motions. Tightness of the iliofemoral ligament, pubofemoral ligament, ischiofemoral ligament, psoas major and/or rectus femoris limit hip flexibility. These constraints have multiple roles in hip mobility, thus affecting numerous motions. Hip abduction, adduction, internal rotation and external rotation are directly influenced by the same tissues that limit hip extension.³² Decreased hip extension could limit almost all other hip joint motions, which may decrease the efficiency of force transfer throughout the hip and torso, leading to compensations viewed as technical errors. The purpose of this study was to identify whether hip extension, internal rotation and external rotation range of motion influences technical errors in baseball pitchers.

CHAPTER III: METHODOLOGY

In this descriptive laboratory study, we determined the association of passive hip range of motion and pitching biomechanical errors in adolescent baseball players. We measured each pitcher's bilateral hip extension, bilateral internal rotation and bilateral external rotation range of motion using a digital inclinometer and performed a video analysis of pitching technique using high-speed cameras.

Participants

Participants were high school male baseball pitchers between the ages of 12 and 17 years old. Participants must have participated as a starter or reliever for at least two seasons. Participants were excluded if they had any injury or pain that prevented normal baseball participation, are sidearm pitchers, or had undergone surgery.⁷⁴ Participants were recruited from local baseball academies in September 2015 through February 2016. An a-priori power analysis for hip extension range of motion correlated with pitching technical errors indicated that in order to detect a moderate correlation ($r=0.4$) with a statistical power of 80% and a type I error rate that is no greater than 0.05, a minimum of 34 participants were needed.

Instrumentation

A universal digital inclinometer (Baseline® Digital Inclinometer, 12-1057) with a 0.3 meter extension arm attachment was used to assess passive hip range of motion. The device provided a range of motion in 1° increments. It was zeroed to the horizontal axis before measuring the subjects' hip extension, internal rotation and external rotation range of motion.

Two high-speed video cameras (Model: Exilim FX-1, Casio Computer Co., Ltd., Tokyo, Japan) were used to record pitching technique. There was a video camera in the frontal view 3 meters in front of the anterior edge of the pitching mound raised to a height of 1 meter.⁷⁴ There was a video camera in the sagittal view, lateral to the pitcher's throwing arm, 3 meters from the side of the pitching mound raised to a height of 1 meter.⁷⁴ Videos from all cameras were captured at 300 frames per second.⁴⁸

Procedures

Informed consent and assent forms were approved by the University of North Carolina at Chapel Hill Institutional Review Board. The adult participants signed consent forms, and assent forms were signed by the underage participants prior to testing. Parental permission forms were signed by the parent or legal guardian of participants between the ages of 12 and 17.

An injury history survey was completed by each of the participants prior to testing. This included questions involving the participants' baseball participation experience, involvement in other athletic teams, pitching experience, and any upper or lower extremity injuries and pain. The baseball participation experience, pitching experience, and injury and pain questions helped the investigator determine if the participant would be included in this study. The upper and lower extremity injury and pain questions began with a *yes* or *no* question if the participant had ever had an upper or lower body injury that has affected pitching participation or performance for at least one week. If the subject marked *yes*, a series of possible injuries was listed for the participant to check. If an injury was sustained, the participant filled in the date the injury first occurred, *yes* or *no* if they saw a physician, and *yes* or *no* if they had surgery for the injury. If the participant has had any upper or lower extremity surgery or injury that prevents normal pitching mechanics, they were excluded from the study. The injury history surveys were assessed after

completion by the examiner for exclusion criteria and used later to look at participant demographics.

Testing Preparation

The film capture took place at an outdoor pitching mound at UNC Chapel Hill or indoor pitching mounds at the local baseball academies. The pitchers had unlimited time to warm-up as needed. The hip range of motion was taken prior to pitching test trials but after warm-up to obtain an accurate measure of range of motion.

Hip Range of Motion Measurements

Each participant's hip range of motion measurements were measured using a digital inclinometer.⁷⁵ Bilateral hip extension, bilateral hip internal rotation and bilateral hip external rotation were measured. There was a total of three trials of each measurement, resulting in a three score average for each variable.

Hip extension was measured using the modified Thomas test. The participant sat at the edge of a plinth, then laid supine and brought the contralateral hip into maximal flexion with both arms, while the ipsilateral leg was lowered towards the ground. The examiner placed the inclinometer along the ipsilateral iliotibial band between the greater trochanter of the femur and lateral femoral condyle.⁷⁵ The inclinometer had an extension arm that reached towards each of the landmarks to ensure accurate inclinometer placement. Once the inclinometer was placed, the examiner recorded the hip extension angle and repeated the process for a total of three trials to be averaged. We previously established intra-rater reliability for hip extension for consistency (ICC (2,k) = 0.971, standard error of measurement (SEM) = 1.32 degrees) and absolute agreement (ICC (2,k) = 0.972, standard error of measurement (SEM) = 1.29 degrees).

Passive internal rotation and external rotation measurements were taken prone with the

hips at 0 degrees of flexion, which is a more functional position for baseball pitchers as compared to having the hips at 90 degrees of flexion. The inclinometer was placed in line with the shaft of the tibia in between the tibial tuberosity and medial malleolus. When the inclinometer was lined to the correct position, the examiner passively brought the participant into the hip range of motion until the first indication of resistance was present. The angle was recorded and the process repeated for a total of 3 trials that were averaged. We previously established intra-rater reliability for hip internal rotation for consistency (ICC (2,k) = 0.962, standard error of measurement (SEM) = 1.22 degrees) and absolute agreement (ICC (2,k) = 0.961, standard error of measurement (SEM) = 1.24 degrees). Similarly, we also established intra-rater reliability for hip external rotation for consistency (ICC (2,k) = 0.977, standard error of measurement (SEM) = 0.88 degrees) and absolute agreement (ICC (2,k) = 0.977, standard error of measurement (SEM) = 0.89 degrees). Total rotational range of motion for the stance and lead leg was calculated from the sum of internal rotation and external rotation for each limb.

Video Analysis of Pitching Mechanics

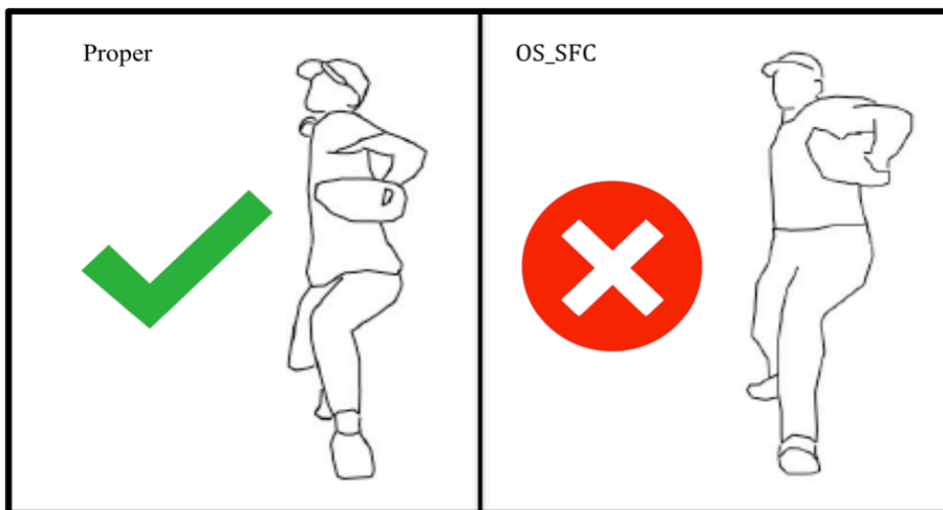
Following the warm-up and the hip range of motion measurement, participants threw 15 fastballs at an intended target a standard distance of 18.39 meters in front of the pitcher's mound. The target was an X marked in the strike zone. The strike zone had a standard width of 0.43 meters, starting 0.46 meters above home plate and ending 1.07 meters above home plate. The fastest 3 strikes were utilized for film analysis. If it took the participant more than 15 pitches to throw 5 strikes, they were given a 30-minute break and the process was repeated, starting with the unlimited warm-up. At that point, if it took the participant more than 15 pitches to throw 5 strikes, they were withdrawn from the study.

Using similar procedures as Oyama et al,⁷⁴ the primary investigator identified the frames of stride foot contact, maximal external shoulder rotation and ball release in both the sagittal and frontal camera views. Stride foot contact was defined as the point in which the foot initially makes contact with the ground. Maximal external rotation was defined as the point immediately before the throwing shoulder begins to rapidly internally rotate, indicating the instance where the shoulder experiences maximal external rotation. Ball release was defined as the instance where the ball left the throwing hand. After the stride foot contact, maximal external rotation and ball release points were determined from each frame they were assessed for the following six errors:

Frontal View:

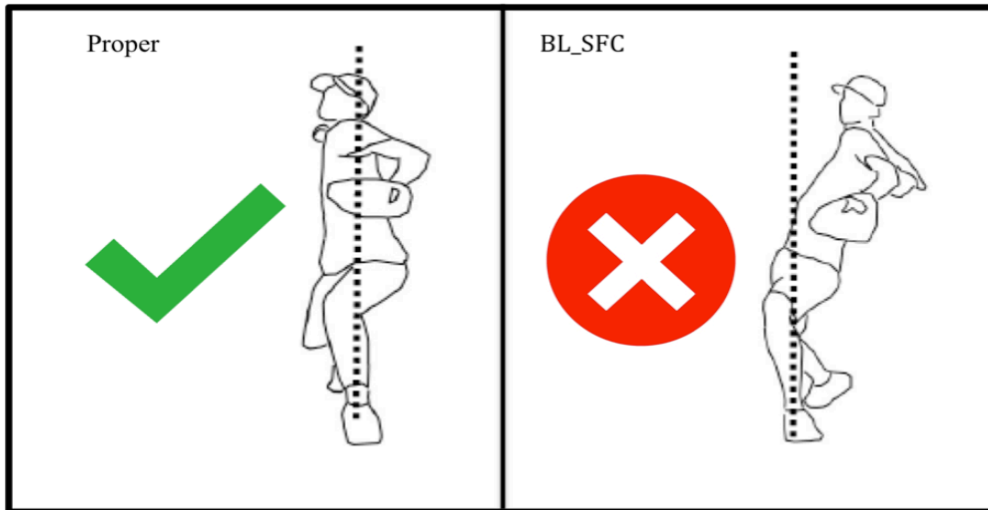
- Stride Foot Contact (SFC)
 - Open shoulder (OS_SFC): anterior aspect of leading shoulder facing the target (**Figure 2**)

Figure 2. Open shoulder at stride foot contact



- Backward trunk lean (BL_SFC): pitcher's head positioned behind vertical line passing through stride foot (ankle) (**Figure 3**)

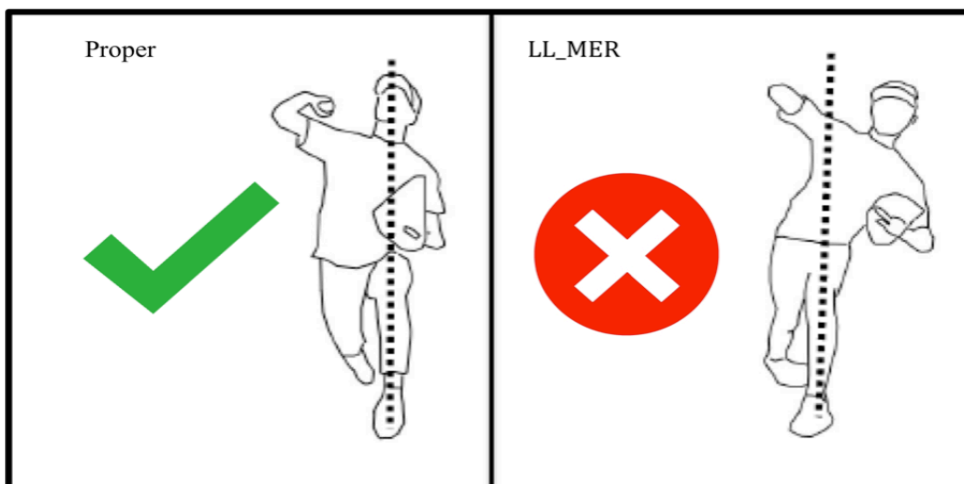
Figure 3. Backwards lean at stride foot contact



- Maximal External Rotation (MER)

- Lateral trunk lean (LL_MER): towards the non-throwing shoulder, lateral deviation of the pitcher's head from vertical line passing through stride foot by more than a head width (**Figure 4**)

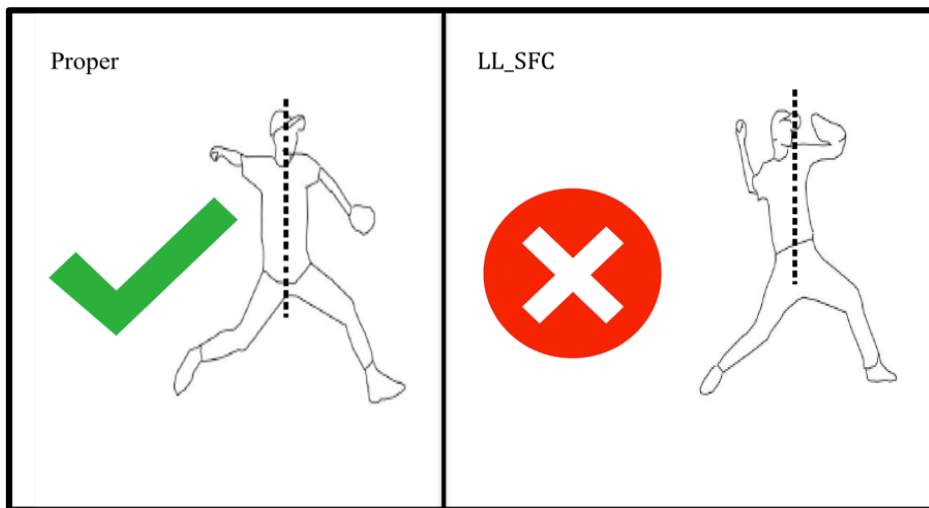
Figure 4. Lateral trunk lean at maximal external rotation



Sagittal View:

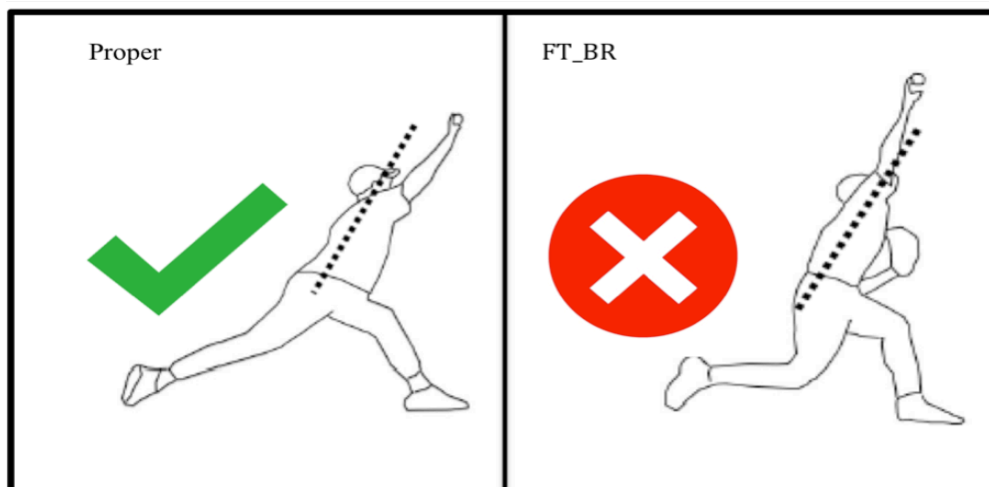
- Stride Foot Contact (SFC)
 - Lateral trunk lean (LL_SFC): towards stance leg, pitcher's head and upper torso not being vertically aligned over umbilicus (**Figure 5**)

Figure 5. Lateral lean at stride foot contact



- Ball Release (BR)
 - Inadequate forward trunk flexion (FT_BR): midline of trunk forward tilted less than 20° (**Figure 6**)

Figure 6. Inadequate forward trunk tilt at ball release



The errors were graded with a “yes” or a “no” depending on if the individual displayed each error (see Appendix 1). Both views were synced in Kinovea© and analyzed for 5 biomechanical errors. Each error was assessed separately in the statistical analysis. Intra-rater reliability for each pitch has been established, shown in **Table 3**.

Table 3. Intra-rater reliability for each of the five technical pitching errors

Trial	OS_SFC	LL_SFC	BL_SFC	LL_MER	FT_BR
1*2	k=0.595 (p=0.012)	k=0.7 (p=0.007)	k=1 (p<0.001)	k=0.667 (p=0.001)	k=0.865 (p=0.006)
% agreement	87%	87%	100%	93%	87%
2*3	k=1.0 (p<0.001)	k=0.526 (p=0.039)	k=0.583 (p=0.024)	k=0.526 (p=0.001)	k=0.857 (p=0.039)
% agreement	100%	80%	87%	93%	80%
1*3	k=0.595 (p=0.012)	k=0.526 (p=0.039)	k=0.583 (p=0.024)	k=0.727 (p=0.003)	k=0.815 (p=0.001)
% agreement	87%	80%	87%	87%	93%

Statistical Analysis

The association between hip range of motion and pitching technical errors was analyzed using a point biserial Pearson r correlation. It compared the stance leg hip extension, bilateral internal rotation and bilateral external rotation measurements (in degrees) to each pitching error. A point biserial Pearson r correlation allows for a dichotomous correlation to be run between a categorical variable (pitching error) and a numerical variable (hip extension in degrees). Each pitching error was graded with a "yes" or a "no". The "yes" grades were given a numerical value of "0" and the "no" grades will be given a value of "1". All analyses had an α level set a priori of 0.05.

CHAPTER IV: MANUSCRIPT

Background: Certain pitching technical errors are linked to increased injurious forces at the upper extremity. Proper pitching mechanics begin at the lower extremity as the force generated at the hips transitions up the kinetic chain to ball release. A decrease in hip range of motion, a common occurrence in adolescent males, could potentially lead to pitching compensations and even increased injury risk. The purpose of this study was to determine if passive hip extension, internal rotation, and external rotation range of motion is associated with baseball pitching technical errors in adolescent baseball pitchers.

Hypothesis: Stance leg hip extension, internal rotation and external rotation range of motion will be associated with pitching technical errors.

Study Design: A descriptive laboratory study.

Methods: 38 male pitchers between the ages of 12 and 17 years old (age: 14.26 ± 1.43 years, height: 170.71 ± 9.51 cm, mass: 61.04 ± 12.49 kg), who participated as a starter or reliever for at least two seasons participated. Following an unlimited individual warm-up, each participant had passive hip range of motion measurements taken then pitched a minimum of 15 fastballs that included a minimum of 5 strikes. Two high speed video cameras (300 frames per second) were used to video tape the pitches in the frontal and sagittal planes. Both views were synced in Kinovea© and analyzed for 5 biomechanical errors (i.e. backwards lean at stride foot contact, open shoulder at stride foot contact, lateral lean at maximal external rotation, lateral lean at stride foot contact and forward trunk tilt at ball release). Point biserial Pearson r correlations were used

to determine the associated between stance leg hip extension, bilateral internal rotation and bilateral external rotation range of motion and pitching technical errors.

Results: Hip extension, internal rotation and external rotation range of motion were not significantly correlated with any of the pitching technical errors.

Conclusions: Although all 5 errors did not show any significant correlations with hip extension, internal rotation nor external rotation range of motion, the data did show that the subjects had overall tight hip range of motion compared to normative values.

Introduction

Baseball is one of the most popular youth sports in the United States.¹ There are nearly 20 million players in organized baseball leagues, with the majority being youth or adolescents.^{2,3} Injury rates in youth pitchers increase due to modifiable risk factors including: pitching mechanics, pitching volume and frequency, muscular imbalances, and lower extremity inflexibility.^{4,5} Fortunately, these factors can be identified during pre-participation examinations in an attempt to prevent overuse injury in adolescents.⁶

Upper extremity overuse injuries are the most frequently occurring, costly pathology in baseball through all levels.^{1,7,8} Overuse injuries are primarily responsible for time loss from sport participation.^{1,8-11} The incidence of injury is heightened because of increased joint and soft tissue loading,¹²⁻¹⁴ that occurs when high stresses and repetitions are placed upon the elbow and shoulder during pitching.¹⁵⁻¹⁷ Overloading soft tissue structures leads to microtrauma that may eventually break down the stabilizing structures if not given adequate time to recover.^{7,15} Specific biomechanical pitching errors have been identified that exacerbate the stress placed upon the joints, increasing injury risk.^{7,16,18-20}

Since the pitching motion starts with leg motion and terminates after the arm propels the ball towards the intended target,²¹ it is important to investigate the lower extremity when assessing pitching biomechanics. The transfer of forces from the lower extremity through the trunk may have effects on upper extremity joint loading since the lower extremity is responsible for up to half of the gross force production during overhead throwing.^{7,27,28} Restricted range of motion at the hip joint has been shown to disrupt pelvic rotation sequencing during pitching; thus, preventing the smooth transfer of force from the lower extremity through the torso to the upper extremity.^{26,28} An alteration in hip external rotation, hip internal rotation or hip extension

range of motion could predispose an athlete to improper pitching mechanics.²⁹ Many previous studies have focused on rotational range of motion,^{8,17,29-31} without studying extension. In the general asymptomatic population, anterior pelvic tilt occurs in about 85% of males and 75% of females,³⁶ implying restricted hip extension range of motion. Tightness at the hip may influence stride length and lead foot placement at stride foot contact,³³ which are responsible for the timing of the pitching sequence. Poor foot positioning at stride foot contact can lead to improper pelvic rotation, resulting in additional technical errors committed up the kinetic chain. Improper pelvic rotation has been shown to influence upper extremity kinetics.¹⁷ Over time with repetitive pitching, it appears that changes in the lower extremity can lead to undesirable changes at the elbow and shoulder.

Faulty biomechanics have been shown to predispose the shoulder and elbow joints to injurious loads.^{12,21-23,38-42} It is possible that hip range of motion restrictions could cause these faulty biomechanics. Thus, the purpose of this study was to determine if hip extension, internal rotation and external rotation range of motion is associated with baseball pitching technical errors in adolescent baseball pitchers. If hip range of motion is associated with pitching errors, ensuring adequate hip flexibility may aid in correcting pitching biomechanics, and has the potential to mitigate upper extremity injurious forces, leading to a decrease in injury rates,^{20,24} time loss and medical expenses.¹

Methods

Participants

Participants were high school male baseball pitchers between the ages of 12 and 17 years of age recruited from local baseball academies. Participants must have participated as a starter or reliever for at least two seasons. They were excluded if they currently had any injury or pain that

prevents normal baseball participation, were sidearm pitchers, or had undergone upper or lower extremity orthopedic surgery.⁷⁴ An injury history survey was completed by each of the participants prior to testing. This included questions involving the participants' baseball participation experience, involvement in other athletic teams, pitching experience, and any upper or lower extremity injuries and pain. The baseball participation experience, pitching experience, and injury and pain questions helped the investigator determine if the participant would be included in this study. If the participant had any upper or lower extremity surgery or injury that prevents normal pitching mechanics, they were excluded from the study. An a-priori power analysis for hip extension range of motion correlated with pitching technical errors indicated that in order to detect a moderate correlation ($r=0.4$) with a statistical power of 80% and a type I error rate that is no greater than 0.05, a minimum of 34 participants were needed.

Hip Range of Motion Measurements

Prior to any data collection, the pitchers had unlimited time to warm-up as needed. A digital inclinometer (Baseline® Digital Inclinometer, 12-1057) with a 0.3 meter extension arm attachment was used to assess passive hip extension, internal rotation and external rotation range of motion. The device provided a range of motion in 1° increments. There was a total of three trials of each range of motion, resulting in a three score average for each range of motion.

Hip extension was measured using the modified Thomas test (see **Figure 1**). The participant sat at the edge of a plinth, then laid supine and brought the contralateral hip into maximal flexion with both arms, while the ipsilateral leg was lowered towards the ground. The examiner placed the inclinometer along the ipsilateral iliotibial band between the greater trochanter of the femur and lateral femoral condyle.⁷⁵ The inclinometer had an arm that reached towards each of the landmarks to ensure accurate inclinometer placement. Once the inclinometer

was placed, the examiner recorded the hip extension angle and repeated the process for a total of three trials to be averaged. We previously established intra-rater reliability for hip extension for consistency (ICC (2,k) = 0.971, standard error of measurement (SEM) = 1.32 degrees) and absolute agreement (ICC (2,k) = 0.972, standard error of measurement (SEM) = 1.29 degrees).

Figure 1. Modified Thomas test to measure hip extension



Passive internal rotation (**Figure 2**) and external rotation (**Figure 3**) measurements were taken prone with the hips at 0 degrees of flexion, which is a more functional position for baseball pitchers as compared to having the hips at 90 degrees of flexion. The inclinometer was placed in line with the shaft of the tibia in between the tibial tuberosity and medial malleolus. When the inclinometer was lined to the correct position, the examiner passively moved the participant into internal and external hip rotation until the first indication of resistance was present. The angle was recorded and the process repeated for a total of 3 trials that were averaged. We previously established intra-rater reliability for hip internal rotation for consistency (ICC (2,k) = 0.962, standard error of measurement (SEM) = 1.22 degrees) and absolute agreement (ICC (2,k) = 0.961, standard error of measurement (SEM) = 1.24 degrees). Similarly, we also established intra-rater

reliability for hip external rotation for consistency (ICC (2,k) = 0.977, standard error of measurement (SEM)=0.88 degrees) and absolute agreement (ICC (2,k) = 0.977, standard error of measurement (SEM)=0.89 degrees). Total rotational range of motion for the stance and lead leg was calculated from the sum of internal rotation and external rotation for each limb.

Figure 2. Prone passive hip internal rotation measurement



Figure 3. Prone passive hip external rotation measurement



Video Analysis of Pitching Mechanics

The video capture took place at outdoor or indoor pitching mounds at local baseball academies, depending on the availability of the pitching mound. Two high-speed video cameras (Model: Exilim EX-F1, Casio Computer Co., Ltd., Tokyo, Japan) were placed in the frontal and sagittal planes to record pitching technique. The frontal camera was placed 3 meters in front of the anterior edge of the pitching mound raised to a height of 20 centimeters. The sagittal camera was placed lateral to the pitcher's throwing arm, 3 meters from the side of the pitching mound raised to a height of 1 meter.⁷⁴ Videos from all cameras were captured at 300 frames per second.⁴⁸

Following the warm-up and the hip range of motion measurement, participants threw 15 fastballs at an intended target at a standard distance of 18.39 meters in front of the pitcher's mound. The strike zone had a standard width of 0.43 meters, 1.07 meters above home plate. The fastest three strikes were utilized for film analysis. If it took the participant more than 15 pitches to throw 5 strikes, they were given a 30-minute break and the process was repeated, starting with the unlimited warm-up.

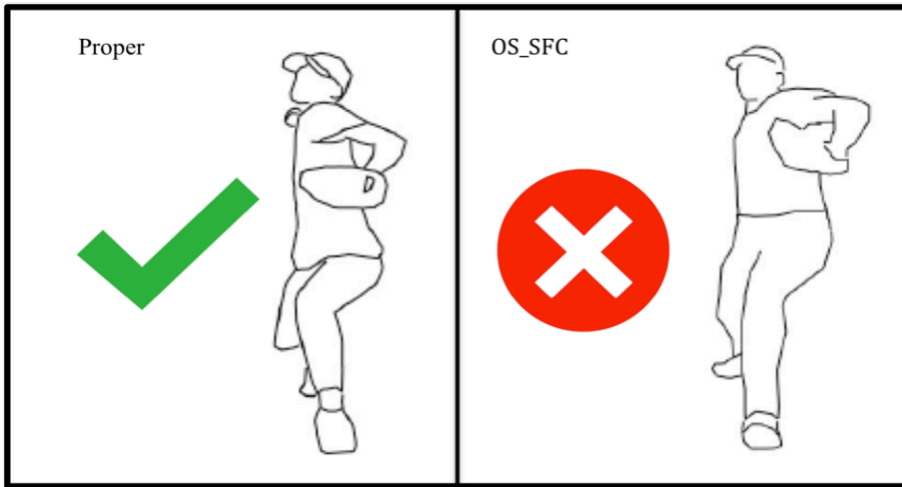
Data Reduction

The primary investigator identified the frames of stride foot contact, maximal external shoulder rotation and ball release in both the sagittal and frontal camera views.⁷⁴ Stride foot contact was defined as the point in which the foot initially makes contact with the ground. Maximal external rotation was defined as the point immediately before the throwing shoulder begins to rapidly internally rotate, indicating the instance where the shoulder experiences maximal external rotation. Ball release was defined as the instance where the ball leaves the throwing hand. The following 5 errors were assessed at these defined time points:

Frontal Plane:

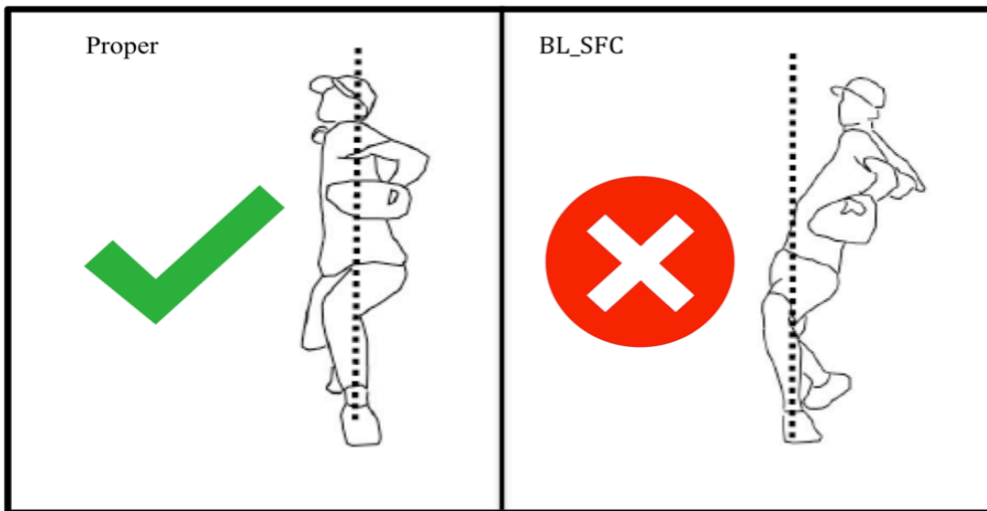
- Stride Foot Contact (SFC)
 1. Open shoulder (OS_SFC): anterior aspect of leading shoulder facing the target (**Figure 4**)

Figure 4. Open shoulder at stride foot contact



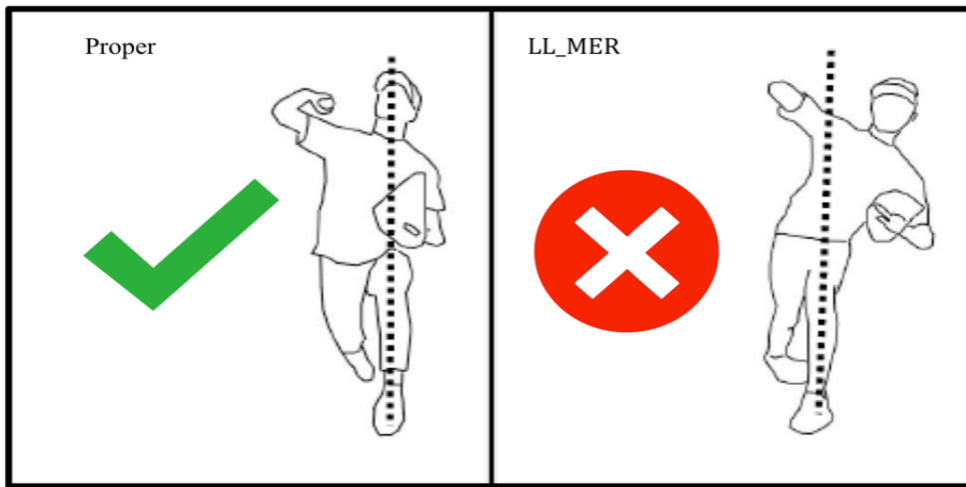
2. Backward trunk lean (BL_SFC): pitcher's head positioned behind vertical line passing through stride foot (ankle) (**Figure 5**)

Figure 5. Backwards lean at stride foot contact



- Maximal External Rotation (MER)
 - 3. Lateral trunk lean (LL_MER): towards the non-throwing shoulder, lateral deviation of the pitcher's head from vertical line passing through stride foot by more than a head width (**Figure 6**)

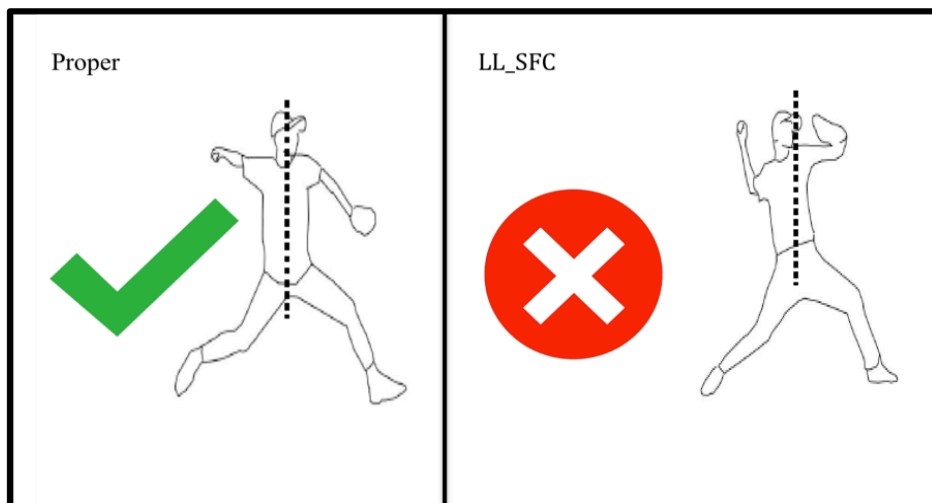
Figure 6. Lateral trunk lean at maximal external rotation



Sagittal Plane:

- Stride Foot Contact (SFC)
 - 4. Lateral trunk lean (LL_SFC): towards stance leg, pitcher's head and upper torso not being vertically aligned over umbilicus (**Figure 7**)

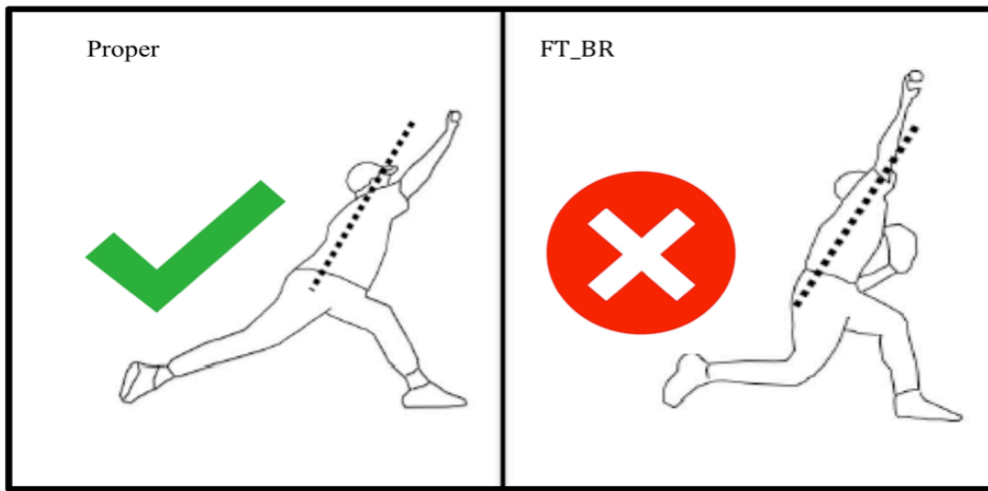
Figure 7. Lateral lean at stride foot contact



- Ball Release (BR)

5. Inadequate forward trunk flexion (FT_BR): midline of trunk forward tilted less than 20° (**Figure 8**)

Figure 8. Inadequate forward trunk tilt at ball release



The errors were graded with a “yes” or a “no” depending upon if the individual displayed each error (see Appendix 1). Both views were synced in Kinovea© and analyzed for 5 biomechanical errors. Each error was assessed separately in the statistical analysis.

Statistical Analysis

Each pitching error was graded with a "yes" or a "no". The "yes" grades were given a numerical value of "0" and the "no" grades were given a value of "1". Hip extension, internal rotation and external rotation range of motion was expressed in degrees. A point biserial Pearson correlation was used to determine the association between the continuous stance leg hip extension, bilateral hip internal rotation, bilateral hip external rotation variables and each dichotomous pitching error variable. All analyses had an α level set priori of 0.05. Statistical analyses were run using SPSS version 21.0 (SPSS Inc., Chicago, IL).

Results

The study included 38 male participants who had pitched a minimum of two seasons. Participant demographics are shown in **Table 1**. All participants were able to pitch at least 5 strikes out of 15 fastballs. The frequency of errors in the participants can be found in **Table 2**. Average values for hip range of motion can be found in **Table 3**. Stance leg hip extension, internal rotation and external rotation range of motion was not significantly correlated between any of the technical pitching errors (**Table 4**). The participants exhibited anywhere from 0 to 5 total technical errors. The most common error exhibited was lateral lean at maximal external rotation followed by forward trunk tilt at ball release.

Table 1. Participant Demographics

	Mean \pm SD	Range
Age (yrs)	14.3 \pm 1.4	12.0 – 17.0
Mass (kg)	61.0 \pm 12.5	39.5 – 91.3
Height (cm)	170.7 \pm 9.5	152.4 – 193.0
Years of Participation	8.9 \pm 2.4	3.0 – 14.0
Years of pitching	5.3 \pm 2.1	1.0 – 9.0
Seasons pitched in past year	2.9 \pm 0.4	1.0 – 3.0
Average Velocity (m/s)	29.7 \pm 3.3	21.8 – 36.6

Table 2 Error frequency and percentage of participants that displayed each error

	Frequency	Percentage
OS_SFC	9	24%
BL_SFC	14	37%
LL_MER	18	47%
LL_SFC	7	18%
FT_BR	15	39%

Table 3 Hip Range of Motion (°). Lead and stance leg hip extension (EXT), external rotation (ER), internal rotation (IR) and total rotation (TR)

	Lead	Stance
	Mean±SD	Mean±SD
EXT	4.6 ± 9.3	4.8 ± 9.2
ER	32.7 ± 6.5	29.7 ± 6.4
IR	31.3 ± 8.1	31.6 ± 8.5
TR	64.1 ± 10.6	64.1 ± 9.8

Table 4 Point biserial Pearson r correlation results r (p) for hip extension (EXT), external rotation (ER), internal rotation (IR) and total rotation (TR) range of motion values for each error: open shoulder at stride foot contact (OS_SFC), backwards lean at stride foot contact (BL_SFC), lateral lean at maximal external rotation (LL_MER), lateral lean at stride foot contact (LL_SFC) and forward trunk flexion at ball release (FT_BR).

		OS_SFC	BL_SFC	LL_MER	LL_SFC	FT_BR
EXT	Stance	0.210 (0.899)	-0.074 (0.655)	-0.107 (0.516)	-0.022 (0.896)	-0.072 (0.663)
ER	Lead	-0.143 (0.392)	-0.193 (0.247)	-0.133 (0.425)	0.110 (0.512)	0.260 (0.877)
	Stance	0.270 (0.102)	0.460 (0.783)	0.360 (0.832)	0.074 (0.660)	-0.400 (0.813)
IR	Lead	0.285 (0.083)	-0.142 (0.394)	-0.243 (0.141)	-0.069 (0.680)	-0.168 (0.314)
	Stance	-0.019 (0.910)	-0.172 (0.307)	-0.258 (0.118)	-0.056 (0.740)	0.101 (0.546)
TR	Lead	0.066 (0.692)	-0.235 (0.156)	0.252 (0.127)	0.041 (0.805)	-0.083 (0.618)
	Stance	0.221 (0.182)	-0.073 (0.662)	-0.139 (0.407)	0.027 (0.871)	0.032 (0.849)

Discussion

The purpose of this study was to determine if passive hip extension, internal rotation and external rotation range of motion were associated with baseball pitching technical errors in adolescent baseball pitchers. It was hypothesized that restricted hip extension, internal rotation and external rotation range of motion would be associated with pitching technical errors. However, there were no significant correlations between passive hip extension, internal rotation, external rotation and each of the five technical errors. Although it has been shown that hip motion is critical in dynamic sequencing of pitching, passive hip range of motion may not

necessarily be a good indicator of dynamic hip motion during pitching. An athlete with restricted passive range of motion could overcome that restriction by recruiting other active tissues.

Tightness of the anterior hip musculature and ligamentous structures that limits hip extension could be counteracted by strong dynamic hip extensors. Future studies should measure active hip range of motion and compare the values to pitching technical errors.

While this study did not support the hypothesis that there is a correlation between hip range of motion and technical errors, it is still believed to play a crucial role in efficient energy transfer from the lower to upper body in the pitching kinematic sequence. Smooth force transfer from the lower extremity through the torso to the upper extremities depends upon the ability to produce sufficient pelvic rotation. Range of motion restrictions have been shown to alter this pelvic rotation,^{26,28} which could predispose an athlete to improper pitching mechanics.²⁹ Fortenbaugh et al²³ reports that improper biomechanics and fatigue can contribute to greater loads on upper extremity joints. To safely increase ball velocity, kinetic variables throughout the whole movement must also increase, starting first in the lower body then transitioning the force to the upper body.²³ Otherwise, the throwing arm will be overloaded as force will then be produced by the upper extremity instead of the lower extremity, resulting in excess stress upon the elbow and shoulder.^{23,25}

Most adolescent males displayed less hip flexibility in this study compared to other studies. Even though there was no correlation established between hip range of motion and pitching technical errors, this study determined normative data for hip extension, internal rotation and external rotation ranges of motion in adolescent male pitchers. Normal hip range of motion measurements for the general population are reported as 25-35° for internal rotation, 35-45° for external rotation and 15-20° for extension.³² To date, this is the only study known that reports on

hip ranges of motion in adolescent baseball players ages 12-18 years. Previous studies have studied prone passive internal rotation and external rotation hip range of motion in collegiate and professional baseball players. Laudner et al²⁹ reported average lead leg total rotation range of motion ($63.4 \pm 7.0^\circ$) and average stance leg total rotation range of motion ($64.2 \pm 8.4^\circ$) in 34 collegiate players. Robb et al³⁴ reported average lead leg total rotation range of motion ($67.0 \pm 7.4^\circ$) and average stance leg total rotation range of motion ($94.8 \pm 13.3^\circ$) in 19 professional players. The 38 adolescent male pitchers in this study presented with less total rotational range of motion (IR+ER) than previous cohorts of baseball players.^{29,34} This study found average lead leg total rotation range of motion ($64.05 \pm 10.6^\circ$), average stance leg total rotation range of motion ($61.27 \pm 9.82^\circ$) and average stance leg hip extension ($4.76 \pm 9.23^\circ$). It is possible that the younger athletes have less total motion than the professional athletes due to the rapid development that adolescents are experiencing from ages 12-18. This may cause increased flexibility restrictions as bones grow and soft tissue structures become more taut during puberty. In addition, professional athletes are more experienced in pitching due to the age difference. They are more likely to have had coaching on specific warmup techniques as well as devoting more time to stretching. The aforementioned studies suggest that lesser hip range of motion may increase the ability to transfer momentum throughout the pitching sequence. However, an increased ability to transfer force through the lower extremity to the upper extremity may be determined by the amount of pitching experience or technique coaching.

Previous studies have identified technical errors with increased joint forces, potentially leading to increased stresses upon the shoulder and elbow.^{7,53,56,60} Davis et al⁵³ was one of the first studies to research the affects of pitching errors on joint loading. They showed that an open shoulder was linked to greater elbow varus and shoulder internal rotation moments. Aguineldo et

al⁵⁶ and Matsuo et al⁶⁰ also showed increased elbow varus moment with lateral trunk tilt. Aguinaldo et al⁷ reported increased elbow varus moments in pitchers who demonstrated premature upper torso rotation. This was displayed by upper torso rotation before stride foot contact, analogous to the OS technical error that was used in this study. Each error was exhibited by 18-39% of participants (see **Table 5**). Additional studies have looked at hip flexibility in relation to increased joint forces.^{17,29} Laudner et al²⁹ reported a decrease in lead leg total rotational range of motion associated with an increase in shoulder external rotational torque. Wight et al¹⁷ found that a closed pelvis orientation at stride foot contact led to greater shoulder and elbow joint loads. These authors have shown that hip flexibility affects joint loading in the upper extremity during pitching. Potentially, detecting technical pitching errors alone may not be sensitive enough to determine increased joint loading that could lead to injuries.

Oyama et al²² examined trunk rotation sequencing in pitchers and noted that pitchers who achieved maximum pelvis angular velocity later experienced increased shoulder kinematics. It is speculated that if a pitcher achieves maximum pelvic angular velocity earlier in the pitching sequence, then the transfer of force from the lower extremity to the upper extremity becomes more efficient. This supports the hypothesis in this study that a decrease in passive hip range of motion may increase upper extremity forces. However, the results of this study did not support the hypothesis. Scher et al⁸ looked at passive hip and passive shoulder range of motion compared to injury history and found that an increase in stance leg hip extension was associated with an increase in throwing shoulder external rotation in pitchers with injury histories. The results from our current study do not support this finding, as hip extension was not correlated with increased technical errors, which have been linked to increased injurious forces at the upper extremity. However, due to kinematic variables not being tested in this study, it was difficult to determine

whether or not the upper extremities were subjected to greater joint loading in participants that displayed restricted hip ranges of motion.

This study presents with multiple limitations. One limitation is the collection of the hip range of motion measurements. Although the procedure for the modified Thomas test was explained to the participant, not every participant followed directions closely. Even after cueing, some of the subjects were not able to relax consistently. This possibly hindered the ability of the investigator to obtain precise measurements. Other participants were not able to hold their contralateral knee to their chest due to tightness of the posterior musculature (i.e. gluteals, hamstrings, etc.). Other factors that may have contributed to the results include participant experience and previous technique coaching. Baseball participation experience ranged from 3 to 13 years. Pitching experience ranged from 1 to 9 years, with an average of 2.88 ± 0.40 seasons pitched within the past year. Spring, summer and fall were all considered individual seasons in the questionnaire. Subjects may have had previous coaching sessions and were coached on technique. This could suggest that technical errors are more affected by previous formal training rather than hip flexibility, which is an idea that should be explored in future research.

There are many other aspects for future research that should be considered. In the present study, there were many different styles of warm-ups completed. They ranged from no warm-up to dynamic warm-ups with throwing. Different warm-up styles and how they relate to pitching technical errors is one area that could be explored. As previously mentioned, kinematic variables were not tested in this study. Future research could include correlations between hip range of motion and upper extremity kinematics. This could also incorporate pitching technical errors to quantify whether or not hip flexibility affects joint loading. Active hip range of motion measurements would be an important progression of this study. Passive and active structures

both contribute to hip extension, internal rotation and external rotation. Testing hip extension, internal rotation and external rotation in the closed kinetic chain would perhaps be the best reflection of hip motion during baseball pitching.

Clinical Significance

Previous research has shown that restricted hip flexibility is related to upper extremity injury risk in baseball pitching.^{17,29} Despite this study not finding significant correlations between hip range of motion measurements and pitching technical errors, lower extremity flexibility is still thought to be an important aspect of injury prevention.

Conclusion

Passive hip extension, internal rotation, and external rotation ranges of motion were not correlated with pitching technical errors. Active hip range of motion measurements may be a better reflection of hip movement during a dynamic motion such as baseball pitching. Future research should focus on active range of motion measurements in correlation with pitching technical errors.

APPENDIX 1: PITCHING ERROR SCORING SYSTEM

Subject # _____	Video Date _____	
Evaluator _____	Date of Evaluation _____	
Pitch # 1		
Frontal Plane View	No Error	Error
1. Backward Lean @ SFC	<input type="checkbox"/> Head and ankle in line	<input type="checkbox"/> Head is lateral to perpendicular line through the ankle
2. Open Shoulder @ SFC	<input type="checkbox"/> Lateral Shoulder Faces Home	<input type="checkbox"/> Sternum is visible
3. Contralateral Trunk Lean @ Max shoulder ER	<input type="checkbox"/> Head, Torso, Ankle in Line	<input type="checkbox"/> Head is lateral to perpendicular line the ankle
Sagittal Plane View	No Error	Error
5. Lateral Lean @ SFC	<input type="checkbox"/> Head over line through umbilicus	<input type="checkbox"/> Head posterior to line through umbilicus
6. Trunk Flexion Angle @BR	<input type="checkbox"/> > 20 degrees	<input type="checkbox"/> < 20 degrees
Evaluator's Notes: _____		
		Total # Errors: _____

APPENDIX 2: ASSENT FORM FOR PARTICIPANTS AGES 12-14 YEARS

**University of North Carolina at Chapel Hill
Assent to Participate in a Research Study
Minor Subjects (12-14 yrs)**

Consent Form Version Date: 5/28/15

IRB Study # 15-1316

Title of Study: Hip Flexibility Associated with Pitching Technical Errors

Person in charge of study: Catherine Miller

Where they work at UNC-Chapel Hill: Exercise and Sport Science

Other people working on this study: Joseph Myers, Matthew Harkey, William Prentice, Terri-Jo Rucinski

These are some things we want you to know about research studies:

Your parent needs to give permission for you to be in this study. You do not have to be in this study if you don't want to, even if your parent has already given permission.

You may stop being in the study at any time. If you decide to stop, no one will be angry or upset with you.

Why are they doing this research study?

The purpose of this study is to determine if hip flexibility affects how you throw. By studying the affect that the hips have on pitching technique, this could provide information that helps to prevent injury. This would let sports medicine professionals, coaches, and others who are involved with baseball to look at pitching technique and decide if there are factors which may cause serious shoulder and/or elbow injuries.

Why are you being asked to be in this research study?

You are being asked to be in the study because you are a male between the ages of 12-14 years old and have participated as a starter or reliever for at least two seasons.

Are there any reasons you should not be in this study?

You should not be in this study if you are a sidearm pitcher or have any on-going injuries that cause you pain when pitching. You will also be excluded if you are unwilling to be video recorded or photographed.

How many people will take part in this study?

If you decide to be in this study, you will be one of about **20** people in this research study.

What will happen during this study?

This study will take place at **this field** and will take no longer than 5 hours. There will be no follow-up.

Testing Preparation

You will report to Ehringhaus field on the UNC campus, located on Ridge Road across from Ram's Deck parking garage. If you have any questions about directions, please contact Catherine Miller by phone. After you sign this assent form, you will fill out the injury history survey. If you have any on-going injuries that prevent you from pitching without pain, you will be excluded from this study. Before starting the study, you will be allowed to warm up as you normally would before a practice or game. After you complete your practice pitches, you will tell one of the researchers on a scale of 1-10 how much pain you are feeling in your pitching arm.

Hip Range of Motion Measurements

After completing your warmup but prior to pitching, you will be asked to lie on a table for hip range of motion testing. You will be lying on your back, holding one knee to your chest in order to measure hip extension. You will be lying on your stomach with a cloth strap around your waist to stabilize your pelvis in order to measure hip external and hip internal rotation. Each measurement test will be done three times on each side.

Filming of the Pitching

You will then be instructed to pitch only fastballs as fast and as well as you can, aiming for the "X" on the backstop that marks the strike zone. Pitches that will qualify for the study will count if the ball hit the strike zone of the backstop. You will pitch a minimum of 15 good pitches that include a minimum of 5 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds will be given between each pitch. After you complete the 3 good pitches, you will be asked again on a scale of 1-10 how much pain you are feeling in your pitching arm. The videos from the front and side, a video of the strikes, and ball speed will be captured for each pitch.

Who will be told the things we learn about you in this study?

The only people who will have access to the things we learn about you in this study are the researchers listed at the beginning of this form.

We will not tell anyone what you tell us without your permission unless there is something that could be dangerous to you or someone else.

What are the good things that might happen?

Research is designed to benefit society by gaining new knowledge. The benefits to you from being in this study may be to assess your potential pitching mistakes or injury risk and be able to correct them before injury happens.

What are the bad things that might happen?

Sometimes things happen to people in research studies that may make them feel bad. These are called "risks." The risk of this study is a 1-10% chance of minimal pain in your throwing arm. A proper warm up should stop this minimal pain from happening to you.

Risks may happen to you. None of them may happen or things may happen that the researchers don't know about. You should report any problems to the researcher.

Will you get any money or gifts for being in this research study?

You will be given a copy of the videos to use any way you see fit. In previous studies, participants shared their videos with their coaches and parents.

Who should you ask if you have any questions?

If you have questions you should ask the people listed on the first page of this form. If you have other questions, complaints or concerns about your rights while you are in this research study you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

If you sign your name below, it means that you agree to take part in this research study.

Sign your name here if you want to be in the study Date

Print your name here if you want to be in the study

Signature of Research Team Member Obtaining Assent Date

Printed Name of Research Team Member Obtaining Assent

APPENDIX 3: ASSENT FORM FOR PARTICIPANTS AGES 15-17 YEARS

University of North Carolina at Chapel Hill

Assent to Participate in a Research Study

Adolescent Participants age 15-17

Assent Form Version Date: 5/28/15

IRB Study # 15-1316

Title of Study: Hip Flexibility Associated with Pitching Technical Errors

Principal Investigator: Catherine Miller

Principal Investigator Department: Exercise and Sport Science

Principal Investigator Phone number: 630-818-7299

Principal Investigator Email Address: cath814@live.unc.edu

Co-Investigators: Joseph Myers, Matthew Harkey, William Prentice, Terri-Jo Rucinski

Faculty Advisor: Joseph Myers

Faculty Advisor Contact Information: joemyers@email.unc.edu

What are some general things you should know about research studies?

You are being asked to take part in a research study. Your parent, or guardian, needs to give permission for you to be in this study. You do not have to be in this study if you don't want to, even if your parent has already given permission. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this assent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The purpose of this study is to determine if hip range of motion affects biomechanical pitching errors. By studying the affect that the hips have upon pitching technique, this could provide evidence based results in order to enhance injury prevention programs. This would allow sports medicine professionals, coaches, and others who are involved with the sport of baseball to identify poor pitching technique and modifiable risk factors which may cause serious shoulder and/or elbow injuries.

You are being asked to be in the study because you are a male between the ages of 12-19 years old and have participated as a starter or reliever for at least two seasons.

Are there any reasons you should not be in this study?

You should not be in this study if you are a sidearm pitcher or have any on-going injuries that cause pain when pitching. You will also be excluded if you are unwilling to be video recorded or photographed.

How many people will take part in this study?

There will be approximately 20 people in this research study.

How long will your part in this study last?

Each individual participant's involvement will take no longer than 5 hours. There will be no follow-up.

What will happen if you take part in the study?

Testing Preparation

You will report to Ehringhaus field on the UNC campus, located on Ridge Road across from Ram's Deck parking garage. If you have any questions about directions, please contact Catherine Miller by phone. After you sign this assent form, you will fill out the injury history survey. If you have any on-going injuries that prevent you from pitching without pain, you will be excluded from this study. Prior to starting the study, you will be allowed to warm up as they normally would prior to participating in a practice or game. After you complete your practice pitches, you will tell one of the researchers on a scale of 1-10 how much discomfort you are feeling in your pitching arm.

Hip Range of Motion Measurements

After completing your warmup but prior to pitching, you will be asked to lie on a table for hip range of motion testing. You will be lying on your back, holding one knee to your chest in order to measure hip extension. You will be lying on your stomach with a cloth strap around your waist to stabilize your pelvis in order to measure hip external and hip internal rotation. Each measurement test will be done three times on each side.

Filming of the Pitching

You will then be instructed to pitch only fastballs as fast and as accurately as possible, aiming for the "X" on the backstop that marks the strike zone. Pitches that will qualify for the study will count if the ball hit the strike zone of the backstop. You will pitch a minimum of 10 good pitches that include a minimum of 3 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds will be given between each pitch. After you complete the 5 good pitches, you will be asked again on a scale of 1-10 how much discomfort you are feeling in your pitching arm. Videos from the front and side, a video of the back stop (to identify strikes), and ball speed will be captured for each pitch.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. The benefits to you from

being in this study may be to identify your pitching movement errors and injury risk and correct them before injury happens.

What are the possible risks or discomforts involved from being in this study?

There may be slight discomfort experienced during this study. You should report any problems to the researcher.

How will information about you be protected?

Privacy will be ensured as identifiable information will be kept under lock and key in the Neuromuscular Research Laboratory on the University of North Carolina at Chapel Hill campus. During data collection personnel in the laboratory will be limited to only members of the study team.

You *will not* be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. There is an approximate incidence of 1-10% of potential discomfort that can come from lack of a proper warm up. A proper warm up will be ensured by setting a 10-15 minute minimum time prior to beginning the study. A minimum of 10 pitches and a maximum of 15 pitches will be collected for this study. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. You do not give up any of your legal rights by signing this form.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have failed to pitch the 3 qualified pitches within 15 pitches, have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will be given a copy of your videos to utilize any way you see fit. In previous studies, participants shared their videos with their coaches and parents.

Will it cost you anything to be in this study?

There will be no cost to be in this study.

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions about the study (including payments), complaints, concerns, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

Your signature if you agree to be in the study

Date

Printed name if you agree to be in the study

Signature of Research Team Member Obtaining Assent

Date

Printed Name of Research Team Member Obtaining Assent

APPENDIX 4: CONSENT FORM FOR ADULT PARTICIPANTS

University of North Carolina at Chapel Hill

Consent to Participate in a Research Study

Adult Participants

Consent Form Version Date: 5/28/15

IRB Study # 15-1316

Title of Study: Hip Flexibility Associated with Pitching Technical Errors

Principal Investigator: Catherine Miller

Principal Investigator Department: Exercise and Sport Science

Principal Investigator Phone number: 630-818-7299

Principal Investigator Email Address: cath814@live.unc.edu

Co-Investigators: Joseph Myers, Matthew Harkey, William Prentice, Terri-Jo Rucinski

Faculty Advisor: Joseph Myers

Faculty Advisor Contact Information: joemyers@email.unc.edu

What are some general things you should know about research studies?

You are being asked to take part in a research study. To join the study is voluntary.

You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.

You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The purpose of this study is to determine if hip range of motion affects biomechanical pitching errors. By studying the affect that the hips have upon pitching technique, this could provide evidence based results in order to enhance injury prevention programs. This would allow sports medicine professionals, coaches, and others who are involved with the sport of baseball to identify poor pitching technique and modifiable risk factors which may cause serious shoulder and/or elbow injuries.

You are being asked to be in the study because you are a male between the ages of 12-19 years old and have participated as a starter or reliever for at least two seasons.

Are there any reasons you should not be in this study?

You should not be in this study if you are a sidearm pitcher or have any on-going injuries that cause you pain when pitching. You will also be excluded if you are unwilling to be video recorded or photographed.

How many people will take part in this study?

There will be approximately 20 people in this research study.

How long will your part in this study last?

Each individual participant's involvement will take no longer than 5 hours. There will be no follow-up.

What will happen if you take part in the study?

Testing Preparation

You will report to Ehringhaus field on the UNC campus, located on Ridge Road across from Ram's Deck parking garage. If you have any questions about directions, please contact Catherine Miller by phone. After you sign the consent form, you will fill out the injury history survey. If you have any on-going injuries that prevent you from pitching with your normal mechanics, you will be excluded from this study. Prior to starting the study, you will be allowed to warm up as they normally would prior to participating in a practice or game. You will be asked to conduct your normal warm up just as you would prior to practice or a game. After you complete your practice pitches, you will tell one of the researchers on a scale of 1-10 how much discomfort you are feeling in your pitching arm.

Hip Range of Motion Measurements

After completing your warmup but prior to pitching, you will be asked to lie on a table for hip range of motion testing. You will be lying on your back, holding one knee to your chest in order to measure hip extension. You will be lying on your stomach with a cloth strap around your waist to stabilize your pelvis to order to measure hip external and hip internal rotation. Each measurement test will be done three times on each side.

Filming of the Pitching

You will then be instructed to pitch only fastballs as fast and as accurately as possible, aiming for the "X" on the backstop that marks the strike zone. Pitches that will qualify for the study will count if the ball hit the strike zone of the backstop. You will pitch a minimum of 10 good pitches that include a minimum of 3 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds will be given between each pitch. After you complete the 3 good pitches, you will be asked again on a scale of 1-10 how much discomfort you are feeling in you pitching arm. Videos from the front and side, a video of the back stop (to identify strikes), and ball speed will be captured for each pitch.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. The benefits to you from

being in this study may be to assess your potential pitching errors or injury risk factors and be able to correct them before injury occurs.

What are the possible risks or discomforts involved from being in this study?

There may be slight discomfort experienced during this study. You should report any problems to the researcher.

What if we learn about new findings or information during the study?

You will be given any new information gained during the course of the study that may benefit your pitching technique.

How will information about you be protected?

Privacy will be ensured as identifiable information will be kept under lock and key in the Neuromuscular Research Laboratory on the University of North Carolina at Chapel Hill campus. During data collection personnel in the laboratory will be limited to only members of the study team.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. There is an approximate incidence of 1-10% of potential discomfort that can come from lack of a proper warm up. A proper warm up will be ensured by setting a 10-15 minute minimum time prior to beginning the study. A minimum of 10 pitches and a maximum of 15 pitches will be collected for this study. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. You do not give up any of your legal rights by signing this form.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have failed to pitch the 3 qualified pitches within 15 pitches, have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will be provided with a copy of your videos to utilize any way you see fit. In previous studies, participants shared their videos with their coaches and parents.

Will it cost you anything to be in this study?

There will be no cost to be in this study.

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions about the study (including payments), complaints, concerns, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

Signature of Research Participant

Date

Printed Name of Research Participant

Signature of Research Team Member Obtaining Consent

Date

Printed Name of Research Team Member Obtaining Consent

APPENDIX 5: PARENTAL PERMISSION FORM FOR MINOR PARTICIPANTS

University of North Carolina at Chapel Hill Parental Permission for a Minor Child to Participate in a Research Study

Consent Form Version Date: 5/28/15

IRB Study # 15-1316

Title of Study: Hip Flexibility Associated with Pitching Technical Errors

Principal Investigator: Catherine Miller

Principal Investigator Department: Exercise and Sport Science

Principal Investigator Phone number: 630-818-7299

Principal Investigator Email Address: cath814@live.unc.edu

Co-Investigators: Joseph Myers, Matthew Harkey, William Prentice, Terri-Jo Rucinski

Faculty Advisor: Joseph Myers

Faculty Advisor Contact Information: joemyers@email.unc.edu

What are some general things you and you child should know about research studies?

You are being asked to allow your child to take part in a research study. To join the study is voluntary.

You may refuse to give permission, or you may withdraw your permission for your child to be in the study, for any reason, without penalty. Even if you give your permission, your child can decide not to be in the study or to leave the study early.

Research studies are designed to obtain new knowledge. This new information may help people in the future. Your child may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you and your child understand this information so that you and your child can make an informed choice about being in this research study.

You will be given a copy of this permission form. You and your child should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The purpose of this study is to determine if hip range of motion affects biomechanical pitching errors. By studying the affect that the hips have upon pitching technique, this could provide evidence based results in order to enhance injury prevention programs. This would allow sports medicine professionals, coaches, and others who are involved with the sport of baseball to identify poor pitching technique and modifiable risk factors which may cause serious shoulder and/or elbow injuries

Your child is being asked to be in the study because he is a male between the ages of 12-19 years old and has participated as a starter or reliever for at least two seasons.

Are there any reasons your child should not be in this study?

Your child should not be in this study if he is a sidearm pitcher or has any on-going injuries that cause pain when pitching. You will also be excluded if you are unwilling to be video recorded or photographed.

How many people will take part in this study?

There will be approximately 20 people in this research study.

How long will your child's part in this study last?

Each individual participant's involvement will take no longer than 5 hours. There will be no follow-up.

What will happen if your child takes part in the study?

Testing Preparation

You will report to Ehringhaus field on the UNC campus, located on Ridge Road across from Ram's Deck parking garage. If you have any questions about directions, please contact Catherine Miller by phone. After you sign the permission form, your child will fill out the injury history survey. If your child has any on-going injuries that prevent him from pitching with his normal mechanics, he will be excluded from this study. Prior to starting the study, he will be allowed to warm up as he normally would prior to participating in a practice or game. After he completes his practice pitches, he will tell one of the researchers on a scale of 1-10 how much discomfort he is feeling in his pitching arm.

Hip Range of Motion Measurements

After completing the warmup but prior to pitching, your child will be asked to lie on a table for hip range of motion testing. He will be lying on your back, holding one knee to his chest in order to measure hip extension. Your child will be lying on his stomach with a cloth strap around his waist to stabilize his pelvis in order to measure hip external and hip internal rotation. Each measurement test will be done three times on each side.

Filming of the Pitching

He will then be instructed to pitch only fastballs as fast and as accurately as possible, aiming for the "X" on the backstop that marks the strike zone. Pitches that will qualify for the study will count if the ball hit the strike zone of the backstop. He will pitch a minimum of 5 good pitches that include a minimum of 3 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds will be given between each pitch. After he completes the 5 good pitches, he will be asked again on a scale of 1-10 how much discomfort he is feeling in his pitching arm. Videos from the front and side, a video of the back stop (to identify strikes), and ball speed will be captured for each pitch.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. The benefits to your child from being in this study may be identifying his potential pitching errors and to correct them before injury occurs.

What are the possible risks or discomforts involved from being in this study?

There may be slight discomfort experienced during this study. You should report any problems to the researcher.

What if we learn about new findings or information during the study?

You and your child will be given any new information gained during the course of the study.

How will information about your child be protected?

Privacy will be ensured as identifiable information will be kept under lock and key in the Neuromuscular Research Laboratory on the University of North Carolina at Chapel Hill campus. During data collection personnel in the laboratory will be limited to only members of the study team.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your child's information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What will happen if your child is injured by this research?

All research involves a chance that something bad might happen to the participant. This may include the risk of personal injury. There is an approximate incidence of 1-10% of potential discomfort that can come from lack of a proper warm up. A proper warm up will be ensured by setting a 10-15 minute minimum time prior to beginning the study. A minimum of 10 pitches and a maximum of 15 pitches will be collected for this study. In spite of all safety measures, he might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. You do not give up any of your legal rights by signing this form.

What if you or your child wants to stop before your child's part in the study is complete?

You can withdraw your child from this study at any time, without penalty. The investigators also have the right to stop your child's participation at any time. This could be because your child has failed to pitch the 5 qualified pitches within 15 pitches, or has failed to follow instructions, or because the entire study has been stopped.

Will your child receive anything for being in this study?

Your child will be provided with a copy of his videos. In previous studies, participants

shared their videos with their coaches and parents.

Will it cost you anything for your child to be in this study?

There will be no cost to be in this study.

What if you or your child has questions about this study?

You and your child have the right to ask, and have answered, any questions you may have about this research. If there are questions about the study (including payments), complaints, concerns, or if a research-related injury occurs, contact the researchers listed on the first page of this form.

What if there are questions about your child's rights as a research participant?

All research on human volunteers is reviewed by a committee that works to protect your child's rights and welfare. If there are questions or concerns about your child's rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Parent's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily give permission to allow my child to participate in this research study.

Printed Name of Research Participant (child)

Signature of Parent Date

Printed Name of Parent

Signature of Research Team Member Obtaining Permission Date

Printed Name of Research Team Member Obtaining Permission

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