

# The Development of a Novel Pitching Assessment Tool

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## **Abstract**

Posture based ergonomic assessment tools are widely used to evaluate posture and injury risk for many workplace/occupational tasks. To date, there is no validated equivalent that can be used to assess the posture of a pitcher during baseball pitching. Therefore, the purpose of this study was to develop an inexpensive tool which can allow for the rapid assessment of a pitcher's posture at lead foot strike, and establish the inter- and intra- rater reliability of the tool. For this study, 11 participants threw 30 pitches (15 fastballs, 15 curveballs) off an indoor pitching. Full body 3D kinematics were measured using reflective markers attached to anatomical landmarks and rigid bodies attached to body segments using a 10-camera Vicon Motion Capture system along with two high-speed video cameras (rear and side view) to record each pitch during the experimental trials. The kinematic data was analyzed, after which the highest velocity fastball of each of the 11 pitchers was selected for further analysis. A Pitching Mechanics Tool was designed to evaluate 16 different parameters at lead foot strike. Each of the 16 parameters had posture ranges or categories established based on scientific literature. Six evaluators with at least five years of experience working with adult pitchers completed the Pitching Mechanics Tool. Findings showed moderate to good levels of repeatability across multiple sessions as well as across multiple evaluators. Additionally, PMT results suggested that 2D qualitative analysis is a viable alternative to 3D motion capture.

**Keywords:** Pitching Mechanics, Three-Dimensional Motion Capture, Kinematics, Ergonomics

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## List of Abbreviations

BSS – Bambach Saddle Seat  
EGM – Electrogoniometer  
EMG – Electromyography  
GRF – Ground Reaction Force  
IMU – Inertial Measurement Unit  
ICC – Intraclass Correlation Coefficient  
MLB – Major League Baseball  
MSDs – Musculoskeletal Disorders  
MPH – Miles Per Hour  
OUA – Ontario University Athletics  
OWAS – Ovako Working Posture Analysing System  
PMT – Pitching Mechanics Tool  
QAP – Qualitative Analysis Protocol  
QEC – Quick Exposure Check System  
REBA – Rapid Entire Body Assessment  
ROSA – Rapid Office Strain Assessment  
RULA – Rapid Upper Limb Assessment  
TJS – Tommy John Surgery  
TR – Triceps Brachii  
UCL – Ulnar Collateral Ligament  
VIRA – Video-Record Analysis  
V3D – Visual 3D  
WMAS – Wearable Motion Analysis Systems  
2D – Two-Dimensional  
3D – Three-Dimensional



# Chapter 1: Introduction

## 1.1 Background and Research Gaps

Pitching biomechanics change across age and skill levels as well as during fatigue. Numerous studies have identified overuse, high velocities, lack of rest time, and high workloads as root causes for musculoskeletal pitching injuries. It is an epidemic affecting pitchers at all age levels. Lyman and colleagues (2001) showed that 26% of youth pitchers have experienced elbow pain at some point during a season and 32% of youth pitchers have experienced shoulder pain while pitching as well (Lyman et al, 2001). According to The Hardball Times, there were 183 professional pitchers who have thrown at least one inning at the Major League level and have also undergone Tommy John Surgery (TJS) by the end of the 2017 MLB regular season (Roegele, 2018). Despite a reduction in elbow surgery cases over the past two seasons (Roegele, 2018), concerns for a pitcher's arm health still remains high. The biomechanical demands associated with pitching and the repetitive nature of the dynamic task puts an incredible amount of stress on the upper extremities. Between 1996 and 2000, Dr. James Andrews performed 95 TJS on collegiate pitchers. This prevalence has increased as college pitchers had 327 elbow surgeries with Andrews between 2006 and 2010 (Rosenbaum, 2012).

In occupational biomechanics and ergonomics, three primary risk factors for injury are often evaluated, including: force, repetition and posture. Among these three risk factors, posture can often be the most difficult to quantify (Chaffin, Andersson, & Martin, 2006). This holds true with pitching as well, as posture or pitching mechanics have been increasingly difficult to access. To date, a valid and reliable assessment of pitching mechanics can only be completed

using costly and technically challenging motion capture technology that typically requires years of expertise.

Research in pitching mechanics often involves the use of expensive three-dimensional (3D) motion capture systems, typically preventing pitchers from being viewed in game scenarios. Protocols involving 3D motion capture can take a long time to complete, and as a result, there are typically small numbers of participants. 2D motion capture is an alternative to 3D motion capture, but has been shown to be inaccurate when evaluating mechanics (Schurr S.A., et al., 2017). It was determined that there is approximately a 16° difference in precision between 2D and 3D analysis methods (Smith, A.C., et al., 2016). A study composed of 26-healthy adults performed a single-leg squat for the purpose of determining 2D and 3D motion capture of joint displacements at the trunk, knee, hip, and ankle in the frontal and sagittal planes. It was verified that 2D motion capture lacks the same precision as compared to 3D analysis (Schurr S.A., et al., 2017).

The field of occupational biomechanics and ergonomics has long relied on the use of “posture binning techniques” to assess body mechanics in the workplace. This allows for the rapid assessment of a job and quick quantification of injury risk (McAtamney & Corlett, 1993; Sonne et al., 2012). These tools have been thoroughly evaluated for inter- and intra-rater reliability. The development of these tools has been extensive, yet successful for workplace and occupational evaluations; however, only one such tool exists for a similar application related to baseball pitching (Nicholls et al., 2003), but its effectiveness was limited due to poor video camera quality and a subjective qualitative checklist. The study concluded that a complete and accurate diagnosis of a pitcher’s mechanics cannot be made using the Qualitative Analysis

Protocol (Nicholls et al., 2003). Therefore, a more advanced qualitative analysis tool is needed and would be important for measuring pitching biomechanics as it pertains to injury prevention, as well as optimizing performance. Such a tool must incorporate full body evaluations of kinematics, as a pitcher must properly utilize the kinetic chain to produce energy from the ground up and efficiently transfer it throughout the pitching delivery (Calabrese, 2013).

## **1.2 Research Questions**

Can 2D images paired with a questionnaire on a pitcher's body position and joint angles be used to evaluate posture with both high inter-rater and intra-rater reliability? Additionally, can subjective 2D image analysis compare well with 3D motion capture

## **1.3 Hypotheses**

1. The Pitching Mechanics Tool will be reliable as a field-based qualitative measuring tool (as compared to the industry gold standard).
  - The Pitching Mechanics Tool will demonstrate high intra-rater reliability for evaluators across multiple sessions
  - The Pitching Mechanics Tool will demonstrate high inter-rater reliability across multiple evaluators
2. The Pitching Mechanics Tool will provide Chi Square P values of at least 0.5 for all 16 kinematic parameters.

- Validity will be better for larger body parts like the trunk and less valid for smaller body parts such as the forearm and elbow

## **Chapter 2: Literature Review**

### **2.1 Upper Extremity Injuries in Baseball**

Overuse injuries to the throwing arm of pitchers are a common concern when studying injury trends in baseball players (Makhni, et al., 2014). Overuse injuries occur as a result of the accumulation of microtrauma from a repetitive action, which in the case of pitching, is a repetitive dynamic overhand motion used to throw a baseball at maximal effort (Lyman, et al., 2001).

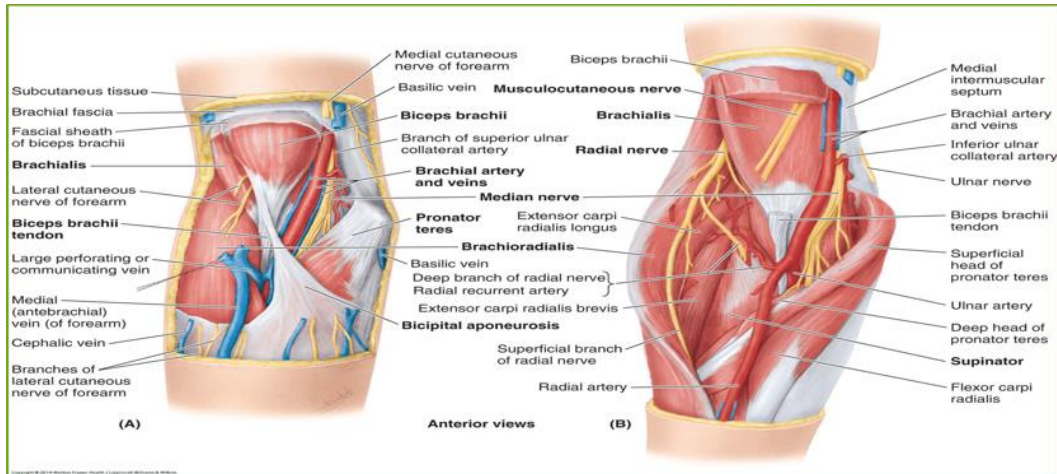
As the incidence of overuse pitching injuries continues to increase at an alarming rate (Makhni, et al., 2014), there has been a greater emphasis placed on factors contributing to injury, such as pitch count, pitch type, and ball velocity (Makhni, et al., 2014). To reduce the growing number of injuries amongst pitchers, the MLB Pitch Smart program has set maximum pitch count recommendations for specific age groups (Table 1). Youth baseball programs such as Perfect Game, USA Baseball, East Coast Pro, and Prep Baseball Report are all in compliance with MLB pitch recommendation regulations.

**Table 1.** MLB Pitch Smart program maximum pitch count recommendations by age group(<http://m.mlb.com/pitchsmart/pitching-guidelines/>)

AGE	DAILY MAX (PITCHES IN GAME)	REQUIRED REST (PITCHES)					
		0 Days	1 Days	2 Days	3 Days	4 Days	5 Days
7-8	50	1-20	21-35	36-50	N/A	N/A	N/A
9-10	75	1-20	21-35	36-50	51-65	66+	N/A
11-12	85	1-20	21-35	36-50	51-65	66+	N/A
13-14	95	1-20	21-35	36-50	51-65	66+	N/A
15-16	95	1-30	31-45	46-60	61-75	76+	N/A
17-18	105	1-30	31-45	46-60	61-80	81+	N/A
19-22	120	1-30	31-45	46-60	61-80	81-105	106+

### 2.1.1 Elbow Anatomy and injuries

The elbow (Figure 1) is a hinge synovial joint that is an articulation of three bones: the humerus, ulna, and radius. On opposing ends of the bones, a protein-based connective tissue called cartilage allows for joints to smoothly slide against one another, while absorbing shock. Ligaments within the elbow hold the bones together. Fluid-filled sacks known as joint capsules surround and lubricate the joints. The medial collateral and lateral collateral ligament are the two main ligaments found in the elbow, and provide stability for the elbow (Savoie, 2017). The radial and ulnar collateral ligaments (UCL) aid the elbow in resisting against varus and valgus forces. The elbow joint functions in flexion and extension.



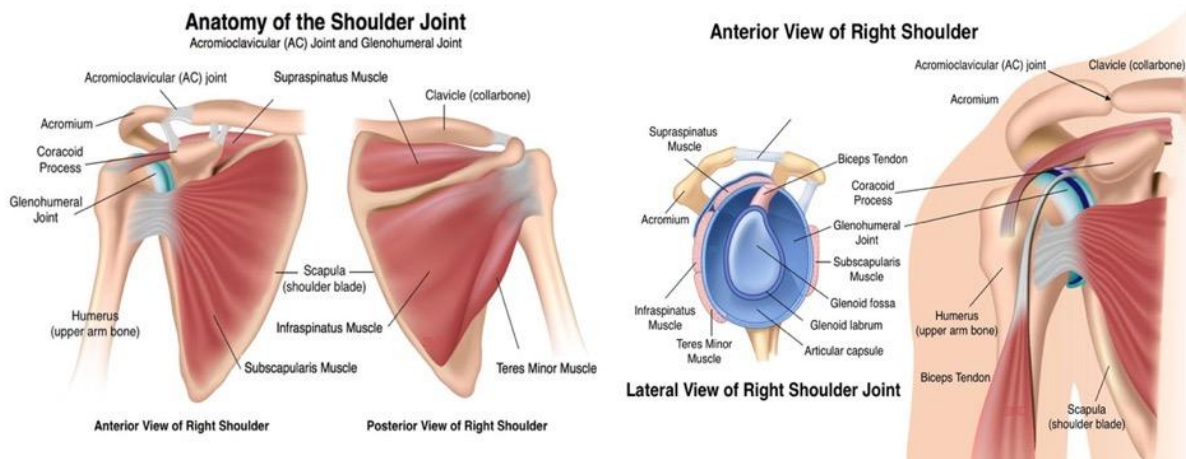
**Figure 1.** Elbow anatomy (<https://www.maxeffortmuscle.com/images/managed/anatomy-of-the-elbow.png>)

In baseball, one of the most prominent elbow injuries is related to the UCL, with estimated rehabilitation time for complete tears ranging from 12 to up to 15 months (Baseball Reference, 2019). The UCL is located on the medial side of the elbow and consists of three divisions: the anterior, posterior, and transverse, with the anterior bundle being integral in elbow stability and resisting against a valgus load (Pribyl, 1999). Through repetitive stress created over time from the overhead throwing motion, the UCL accumulates microtrauma which can initially cause pain, but through continued stress may lead to strains or complete UCL tears. A complete UCL tear requires elbow reconstructive TJS (Wheeler, 2017).

### 2.1.2 Shoulder Anatomy and Injuries

The shoulder is one of the more complex joints in the human body, and is formed at the point at which the humerus fits into the scapula (Figure 2). Other key aspects of the shoulder are the acromion, a bony projection located off the scapula, the clavicle (also referred to as the collarbone), and the coracoid process, which is an additional bony projection located off the

scapula. The shoulder maintains its support and structure from the collection of muscles and tendons surrounding it, known as the rotator cuff. The rotator cuff is protected by a small fluid-filled sac called the bursa (Hoffman, 2017).



**Figure 2.** Shoulder anatomy (<http://www.orthowashington.com/images/shoulder-anatomy.jpg?crc=464368484>)

Although the loose connection between the upper arm and the shoulder allows for a wider range of motion, it also leaves the shoulder susceptible to injury. Pitching through shoulder pain can eventually lead to serious injury, including subacromial bursitis, Bennett lesion, superior labrum anterior-posterior lesion, posterosuperior glenoid impingement, and axial artery compression and thrombosis (Fujisawa, et al., 2002).

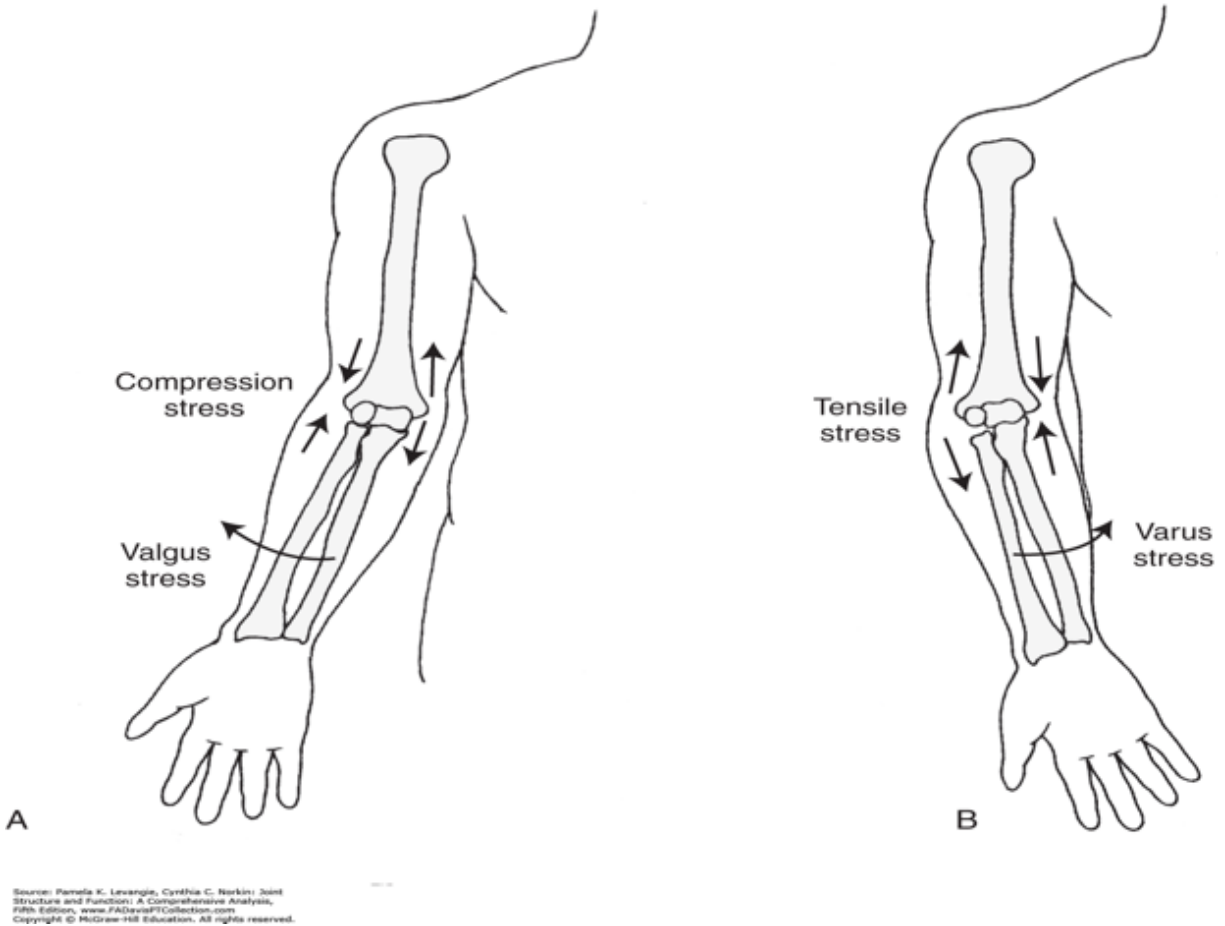
### 2.1.3 Pitching Injuries in Baseball

Improper pitching mechanics has been a suggested risk factor for elbow and shoulder injuries in baseball pitchers of all age groups. As pitchers start to fatigue, they aim to maintain



ball velocity through variations to their throwing kinematics (Seroyer, et al., 2010). With the use of quantitative analysis and high-speed video, 169 baseball pitchers (86 youth, 83 adolescent) were recorded while throwing fastballs to quantify the effects of frequent pitching errors on both joint stress and pitching efficiency. The study then compared the correct performance of five common pitching parameters (leading with the hips, hand on top, arm in throwing position, closed shoulder, stride foot toward home plate) with each pitcher's age, humeral internal rotation torque, elbow valgus load, and calculated pitching efficiency (Davis, et al., 2009). Adolescent pitchers who incorrectly led with the hips were associated with higher normalized humeral internal rotation torque ( $P = .07$ ), higher normalized elbow valgus load ( $P = .047$ ), and lower pitching efficiency ( $P = .045$ ). Meanwhile, the youth pitchers who demonstrated the ability to perform most parameters correctly showed the lowest normalized-humeral internal rotation torque ( $P = .041$ ), lowest normalized elbow valgus load ( $P = .046$ ), and highest pitching efficiency ( $P = .059$ ) and were subsequently less susceptible to elbow and shoulder injury (Davis, et al., 2009).

Biomechanical research has shown that the generation of power during the throwing motion places significant stress on the elbow and shoulder joints. Excessive valgus load (Figure 3) on the elbow could prove to be devastating for pitchers (Fehr, et al., 2016).

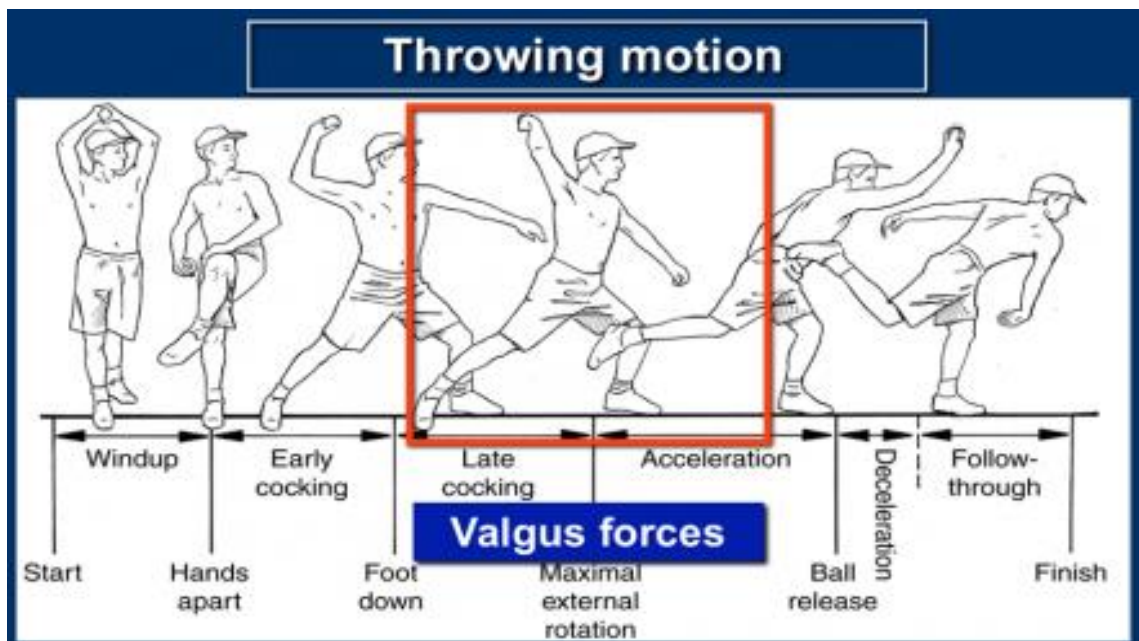


**Figure 3.** Valgus and varus elbow stress (Source: [https://fadavispt.mhmedical.com/data/books/1862/levangiejoint\\_ch8\\_f033.png](https://fadavispt.mhmedical.com/data/books/1862/levangiejoint_ch8_f033.png))

A descriptive laboratory study demonstrated that elbow valgus torque increased with greater shoulder external rotation ( $169^\circ \pm 15^\circ$ ,  $r = .60$ ,  $P < .01$ ), but decreased with more elbow flexion at ball release ( $41^\circ \pm 24^\circ$ ,  $r = -.36$ ,  $P < .01$ ). These findings challenge the long-standing ideology of coaches and scouts who believe that the elbow should be straighter during the pitching delivery (Aguinaldo & Chambers, 2009). A case-control study cited similar results, showing that with increased elbow flexion, elbow valgus torque would decrease, but with a

greater angle of shoulder rotation, a greater valgus load would be placed on the elbow, increasing the risk of medial elbow pain and injury (Fehr, et al., 2016).

For a separate study, 23 professional baseball players, nine of whom were dealing with elbow injuries of varied severity, were videotaped throughout spring training (professional baseball's preseason) and were then tracked further for elbow injury over the next three seasons. Results showed a significant increase in elbow injury with higher elbow valgus torque ( $P = .0547$ ) and higher shoulder external rotation torque ( $P = .0548$ ). Moreover, during the late cocking phase (Figure 4) of the pitching delivery, higher elbow valgus torque ( $P = 0.0130$ ) and higher shoulder external rotation torque ( $P = 0.0018$ ) significantly increased the rate of elbow injury (Anz, et al., 2010).



**Figure 4.** Increase in valgus force during the late cocking and acceleration phase of the pitching motion (Source:

[http://www.radiologyassistant.nl/data/bin/w440/a5210fa2b63846\\_19-throwing2.png](http://www.radiologyassistant.nl/data/bin/w440/a5210fa2b63846_19-throwing2.png))

A cross-sectional survey was conducted on 754 youth baseball pitchers aged nine to 18. The study sought to assess the relationship between self-reported pitching activities, and elbow and shoulder injuries. Findings demonstrated 70% greater odds of arm pain associated with throwing curveballs, while 69.2% of pitchers reported pitching through arm tiredness, and an additional 37.9% reported pitching through arm pain (Yang, et al., 2014).

A longitudinal study attempted to relate the frequency of shoulder and elbow complaints in youth pitchers to pitch types, volume, as well as other common risk factors. Following 298 pitchers over the duration of two years, participants were contacted via telephone for an interview after each game pitched. Of the 298 participants, 26% reported elbow pain and 32% reported shoulder pain (Lyman, et al., 2001). Furthermore, 68% of pitchers who reported elbow pain, cited pain on the medial side of the elbow, while 27% cited pain on the lateral side. Approximately 29% of pitchers who dealt with shoulder pain reported pain on the superior aspect of the shoulder, whereas 20% reported pain located on the anterior, posterior, and lateral aspects of the shoulder. Results also showed increased odds of elbow pain from throwing split-finger pitches, and a decreased likelihood in both shoulder and elbow pain from throwing more changeups (Lyman, et al., 2001). A separate study looked to further determine the effects of pitch type on both elbow and shoulder pain in youth baseball pitchers. Using a sample of 476 pitchers, statistical trends demonstrated a 52% increased risk in shoulder pain via the curveball, and an 86% increased risk in elbow pain via the slide. Changeup usage led to a 12% reduction in elbow pain and a 29% decrease in shoulder pain (Lyman, et al., 2002). A significant correlation was also discovered between pitch count and shoulder and elbow pain, as certain counts would call for specific pitches. The study also noted that 28% of pitchers

reported elbow pain at least once during the span of a baseball season, while 35% of pitchers cited shoulder pain at least once during the season (Lyman, et al., 2002).

Apart from poor pitching mechanics, pitch type, pitch count, and accumulating fatigue, ball velocity is one of the major contributors to upper extremity injury in pitchers. A cohort study composed of 23 professional pitchers saw the top fastball velocity of a pitch thrown for a strike from each participant collected and further analyzed. The group of pitchers were then followed for the next three seasons for elbow injuries that were significant enough to land the pitcher on either the disabled list or warrant surgery. Of the 23 pitchers, nine suffered elbow injuries, three of whom required UCL reconstruction surgery. The injured group had a mean ball velocity of 89.22 mph, whereas the slightly larger non-injured group had a mean ball velocity of 85.22 mph (difference in 4 mph), demonstrating a significant ( $P = .0354$ ) correlation between maximal ball velocity and elbow injury (Bushnell, et al., 2010). The three pitchers who boasted the highest velocities in the study all underwent TJS.

Employing information from a publicly available PitchFx database, data on pitch velocity, number, and type for every pitcher who threw in an MLB game between April 2, 2007 and April 14, 2015 was gathered for the purpose of determining predictive factors of UCL tears (Chalmers, et al., 2016). For the purpose of the case-control study, 1327 pitchers were included, 309 (26.8%) of whom underwent UCL reconstruction surgery. Pre-injury velocity data was available on 145 of the 309 pitchers. Peak fastball velocity was shown to be significantly higher (mean [95% CI], 93.3 mph [92.8-93.8] vs. 92.1 [91.9-92.3];  $P < .001$ ) among pre-injury pitchers than pitchers who did not undergo surgery. Furthermore, 20% of pitchers with peak ball

velocity registered at over 95.7 mph underwent TJS compared to only 7.8% of pitchers with peak ball velocities under 86.9 mph (Chalmers, et al., 2016).

## **2.2 Pitching Mechanics**

### **2.2.1 Pitching Delivery**

The kinetic chain is a process of sequenced body movements and muscular activations in both the upper and lower extremities for the purpose of performing a biomechanical task (Sciascia & Cromwell, 2012). Pitching is a dynamic, overhead throwing movement which relies on the kinetic chain to throw a baseball at high velocity with precise accuracy. An effective pitching delivery begins with the generation of ground reaction force. The lower extremity, pelvis and trunk are tasked with initiating potential force development and creating the base of support necessary to transfer potential energy from the lower half of the body into kinetic energy to the upper half of the body, primarily the shoulder, and the elbow. In turn, the shoulder and elbow are instrumental in driving the force to the baseball as it gets thrown towards home plate (Calabrese, 2013). The pitching delivery itself is broken down into six stages: the wind-up phase, the stride or early cocking phase, the late cocking phase, the arm acceleration phase, the deceleration phase, and the follow-through phase (Figure 3). As pitching mechanics do not undergo significant adjustments between levels of competition, it is essential to teach proper pitching mechanics early in a pitcher's career development in order to minimize future risk of injury, while simultaneously maximize performance (Fleisig, et al., 1999).

#### *Wind-up Phase*

The wind-up phase begins with the pitcher standing with both feet on the rubber. The pitcher then makes their first movement from the static position by lifting their lead leg until maximum knee height is reached. Once peak knee height is reached, it is important to remain balanced as opposed to prematurely motioning forward towards home plate. The ball remains within the glove throughout the windup. Although the wind-up is different for each athlete, as it is very much about comfort, the phase ends at the same point for most pitchers with the knee at maximum height, and the glove and the throwing hand approximately at chest-shoulder height, demonstrating a stable center of gravity (Calabrese, 2013). Of course, outliers such as Clayton Kershaw exist. The All-Star starting pitcher of the Los Angeles Dodgers completes his windup with his hands stationed at head level.

#### *Early Cocking/Stride Phase*

With maximum knee height reached to end the wind-up phase, the lead leg begins to stride forward until lead foot strike as the pitcher accelerates his body linearly towards home plate. In the early cocking phase, a pitcher gathers potential energy, which will then be released during the late cocking and early acceleration phase as kinetic energy (Douoguih, et al., 2015). At this point, a pitcher must be able to take a long stride to increase trunk rotational potential, which in turn will increase the development of potential force. Lead knee extension is dictated by stride length. At the Major League level, most pitchers adopt stride lengths between 80-85% of body height, which contributes to greater knee extension at lead foot strike (Crotin & Ramsey, 2014). The pelvis rotates at 400°-700°/second during the dynamic stride phase as the upper quarter remains relatively still in a closed position, therefore producing spinal rotation (Calabrese, 2013). Hip-to-shoulder separation is another important aspect of the early cocking

phase as it plays a large role in generating the requisite force for increasing a pitcher's ball velocity.

During the stride, the simultaneous activations of the dynamic and static stabilizers of the shoulder allows for the correct positioning of the scapular glenoid and humeral head, in order to minimize physiological tissue overload. The scapula must then rotate upward while assuming a retracted position for the rotator cuff and deltoid to abduct the arm in preparation for early cocking (Calabrese, 2013). Pitchers who demonstrate less shoulder abduction at lead foot strike following the early cocking phase display a reduced level of valgus stress on the elbow (Douoguih, et al., 2015).

The baseball is taken out of the glove as the arm path transitions downward, bringing the hand below the pitcher's hips, then brought up to an elbow height or slightly above the shoulder with an elbow flexion angle between 80°-100°. The throwing hand should be slightly pronated with the baseball facing between second or third base, while the fingers position over the top of it (Calabrese, 2013). Once lead foot strike occurs, the stride foot should either face home plate, or stand slightly closed off towards third base for right-handed pitchers, or towards first base for left-handed pitchers.

#### *Late Cocking Phase*

With the lead foot in contact with the ground, the late cocking phase proceeds up until maximum shoulder external rotation. At this point, the knee begins to extend, while the trunk de-rotates to provide a stable base of support for impending forward trunk flexion. In the late cocking phase, the shoulder is abducted 90°-110° and externally rotated between 50°-185°



(Calabrese, 2013). This abduction range is maintained as the throwing shoulder continues to approach maximum external rotation.

Furthermore, the subscapularis, latissimus dorsi, and pectoralis major contract eccentrically, while the infraspinatus and teres minor contract concentrically to allow the deltoid to reach extreme external rotation. The long head of the bicep provides the humeral head with the help it requires for further compression and stability as humeral external rotation increases past 60° and actively flexes the elbow at maximal shoulder external rotation (Calabrese, 2013). The range of external rotation is somewhat restricted due to the varus torque produced by the UCL, forearm pronators, and the wrist flexors. Prior to the start of the acceleration phase, at maximum external rotation, the shoulder is abducted between 90° to 100° and horizontally adducted up to 20°. Elbow flexion is at approximately 90° (Calabrese, 2013).

#### *Arm Acceleration Phase*

The arm acceleration phase begins at maximum external rotation and continues up until the point of ball release (Calabrese, 2013). From maximum external rotation, there is a shift to rapid shoulder internal rotation and horizontal adduction at a velocity of over 9000°/second, while the elbow reaches 2251°-2728°/second in the scapular plane. During the acceleration phase, the elbow extension angle is at approximately 25°, while shoulder internal rotation, wrist flexion, and pronation are at 90° (Calabrese, 2013).

A comparative electromyographic analysis determined that youth pitchers are at a greater risk of overuse rotator cuff injury than professional pitchers as they exhibit three times greater bicep (48% maximal manual muscle test, MMT, compared to between 12-17% MMT in

professional pitchers) and rotator cuff muscle activity (Gowan, et al., 1987). The abduction angle of the humerus at ball release is maintained by both trunk rotation and lateral flexion. Depending on the angle of lateral trunk flexion, ball release point varies. With excessive flexion, pitchers exhibit an over-the-top arm slot, whereas a decreased angle would create more of a sidearm release point (Calabrese 2013).

#### *Arm Deceleration and Follow-Through Phases*

The deceleration phase begins following ball release and ends with maximal dominant shoulder internal rotation as well as 35° of horizontal adduction. The back foot pushes off and is off the ground during the follow-through as the trunk rotates over the extending lead leg as it descends down the mound towards home plate (Calabrese, 2013).

#### **2.2.2 Fatigue's Effect on Pitching Mechanics**

Muscle fatigue is a process that occurs due to factors involving the brain, otherwise known as central fatigue, or through peripheral mechanisms on the muscular level (Davis, 1995), and typically manifests a decline in maximal force production (Enoka & Duchateau, 2008). As a baseball pitcher fatigues, they experience a change in their pitching kinematics. A study aimed at investigating kinematic and kinetic changes brought on due to fatigue accumulated over extended play videotaped seven MLB pitchers over the duration of a game. Seven parameters showing significant differences between early and late innings (Table 2), including decreases in maximum shoulder external rotation (from 181° in the first inning to 172° in the last), knee angle at ball release (from 140° in first inning to 132° in the last), and maximum distraction force at both the shoulder and the elbow (97% and 85% at the shoulder

and elbow in the first inning, and 88% and 72% in the last) were found from the kinematic analysis (Murray, et al., 2001). A separate study had 28 healthy young pitchers throw 15 fastballs at full-effort per inning for six innings (Table 2). Pitchers were again videotaped for the purposes of kinematic analysis. Data showed that knee flexion at ball release progressively increased with pitch count, while hip-to-shoulder separation significantly decreased with the rise in pitch count. There was also a significant increase in external rotation and total range of motion noticed in the throwing shoulder post-pitching (Erickson, et al., 2016).

**Table 2.** Changes in pitching kinematics due to fatigue

<u>Article Author</u>	<u>Sample Size</u>	<u>Changes in Kinematics Due to Fatigue</u>
Rafael F., Escamilla, et al.	10 collegiate baseball pitchers	With accumulation of muscle fatigue, significant changes seen in trunk position during the arm cocking and acceleration phase ( <i>from <math>34^{\circ} \pm 12^{\circ}</math> to <math>29^{\circ} \pm 11^{\circ}</math></i> )
Tricia A., Murray, et al.	7 major league baseball pitchers	Decreases in maximum external rotation of the shoulder ( <i>from <math>181^{\circ}</math> in the first inning to <math>172^{\circ}</math> in the last</i> ), knee angle at ball release ( <i>from <math>140^{\circ}</math> in first inning to <math>132^{\circ}</math> in the last</i> )
Brandon J., Erickson, et al.	28 elite adolescent pitchers	Hip-to-shoulder separation significantly decreased as pitch count rose ( <i>from <math>90\% \pm 40\%</math> at pitch 15 to <math>40\% \pm 50\%</math> at pitch 90; <math>P &lt; .001</math></i> ).  Knee flexion increased progressively ( <i>from <math>49^{\circ} \pm 15^{\circ}</math> to <math>53^{\circ} \pm 15^{\circ}</math> with pitch number, <math>P = .008</math></i> ).  Significant increase in external rotation and total range of motion observed in the shoulder post pitching ( <i>from <math>P = 0.007</math> to <math>P = 0.047</math></i> ).  Lower half musculature fatigued before changes in upper extremity kinematics occurred
MJ, Mullaney, et al.	13 baseball pitchers	Postgame results showed selective fatigue of <i>15% in shoulder flexion (<math>P = .02</math>), 18% fatigue in shoulder internal rotation (<math>P = .03</math>), and 11% in shoulder adduction (<math>P = .01</math>)</i>
David, Keeley, et al.	10 baseball pitchers	Significant differences were observed in the angle of lateral pelvis flexion at maximum external rotation ( <i>from <math>-10.8 \pm 11.8</math> to <math>-14.8 \pm 11.3</math></i> ) and ball release ( <i>from <math>-3.36 \pm 5.24</math> to <math>-6.82 \pm 3.87</math></i> ) between non-fatigued and fatigued conditions.
Paul P-H, Chou, et al.	16 baseball pitchers	Significant increases in knee flexion ( <i>from <math>53.6^{\circ} \pm 21.5^{\circ}</math> to <math>56.1^{\circ} \pm 22.2^{\circ}</math>; <math>P = .01</math></i> ) and trunk forward tilt ( <i>from <math>21.4^{\circ} \pm 5.4^{\circ}</math> to <math>24.2^{\circ} \pm 6.6^{\circ}</math>; <math>P = .01</math></i> ) at instant of ball release were observed

A laboratory study implemented a lengthy fatigue protocol on 13 pitchers, evaluating each participant before and after 19 games. Participants threw 99 pitches on average across an average of seven innings per game, resulting in selective fatigue, primarily at the shoulder. Decreases in shoulder internal rotation (by 18%;  $P = .03$ ), flexion (by 15%;  $P = .02$ ) and adduction (by 11%;  $P = .01$ ) were noted during postgame testing (Mullaney, 2005).

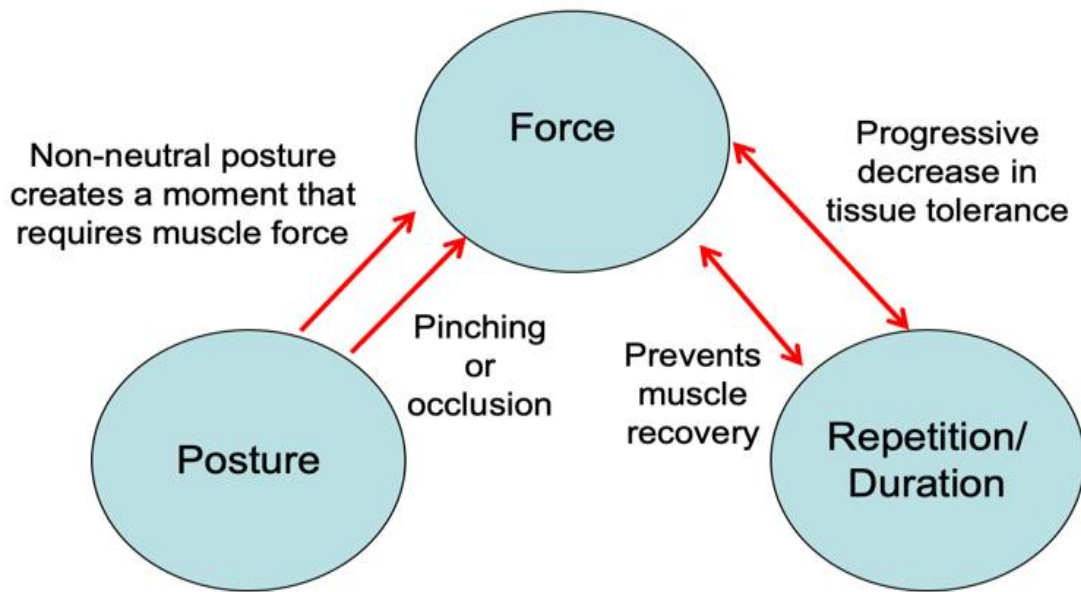
Mechanical changes are most notably seen during the arm cocking and acceleration phases (Table 2). A controlled lab study showed altered trunk flexion (from  $34^\circ \pm 12^\circ$  to  $29^\circ \pm 11^\circ$ ) due to fatigue within both stages (Escamilla, et al., 2007). Other noteworthy signs of fatigue effecting pitching mechanics are increases in knee flexion (from  $53.6^\circ \pm 21.5^\circ$  to  $56.1^\circ \pm 22.2^\circ$ ;  $P = .01$ ) and trunk forward tilt (from  $21.4^\circ \pm 5.4^\circ$  to  $24.2^\circ \pm 6.6^\circ$ ;  $P = .01$ ) at instant of ball release (Chou, 2015). An additional study (Table 2) observed significant differences in the angle of lateral pelvis flexion at maximum external rotation (from  $-10.8 \pm 11.8$  to  $-14.8 \pm 11.3$ ) and ball release (from  $-3.36 \pm 5.24$  to  $-6.82 \pm 3.87$ ) between non-fatigued and fatigued conditions (Keeley, 2010).

### **2.3 Kinematic Risk Assessment Tools**

In the field of occupational ergonomics, there are a variety of tools available which assess the risk factors related to force, repetition, and posture (Figure 5). Most notably, the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) are posture based assessment tools that allow for a quick and inexpensive method of assessing postures related to musculoskeletal injury. The purpose of these tools is to identify risk factors which contribute to injury, then quantify said factors, followed by making measurable improvements

to decrease the likelihood of injury occurrence. The goal is the development of an assessment tool that is easy and quick to complete, observational, valid and reliable. In essence, ergonomics is the ongoing process of risk identification and risk reduction through scientific and biomechanical analysis (Middlesworth, 2018).

In baseball, while there have been tools developed to measure force production and repetition, limited research has been presented which can reliably and validly assess pitching mechanics with limited data collection equipment. To this point, it is imperative to develop an applicable tool which can identify improper pitching mechanics, or changes in pitching mechanics which are associated with fatigue, deterioration in performance, and possible injury.



**Figure 5.** Three main identified risk factors often considered in ergonomic assessment tool design (Potvin, 2017)

### 2.3.1 RULA

RULA is a survey-based screening tool used for evaluating upper limb disorders and overuse injuries created in the workplace (Figure 6). The tool utilizes diagrams of body postures and three separate scoring tables to provide information on potential risk factors. The survey itself does not require any form of equipment to generate an efficient form of assessment of the posture related to the neck, trunk, and upper limbs as well as the muscle function and the external loads experienced by the body. External loads include the number of movements, static muscle work, force, time worked without a break, and work postures due to equipment or furniture (McAtamney & Corlett, 1993). Individual differences taken into consideration included the age and experience of the employee as well as the speed and accuracy of their movements. The RULA tool divides the body into Groups A and B, with A incorporating the upper and lower arm and wrist while B composing of the neck, trunk and legs. Taking the lower body into account is important to account for its influence on upper limb posture.

To provide quantitative feedback, a Grand Score System was developed (Figure 6), combining each body group with scores ranging from one-to-seven plus (one signifying minimal risk, whereas seven-plus signified high risk). At levels three and four, postural changes may be necessary to prevent injury. At levels five and six, further investigation and postural changes should be implemented in the short term. At level seven-plus, further investigation and postural changes must be made immediately.

A study attempted to utilize RULA, albeit in the absence of high force exertion, in order to evaluate the correlation between self-reported musculoskeletal disorders and levels of ergonomic risk related to smartphone usage. The study required 30 participants with no prior

history of traumatic injury to fill out a survey and complete a seated smartphone texting task during which their postures were video recorded and then assessed by three independent researchers (Namwongsa, et al., 2018). Results showed the greatest scores in the neck, trunk and leg posture with mean scores of  $3.73 \pm 0.691$ ,  $3.30 \pm 0.988$ , and  $1.70 \pm 0.466$ , respectively. The final RULA Grand Score ranged from six ( $n = 24$ , 80%) to seven ( $n = 6$ , 20%) for the left side and a minimum score of 4 ( $n = 1$ , 3.30%), a mode score of 6 ( $n = 27$ , 90%), and a maximum score of 7 ( $n = 2$ , 6.70%), indicating a need for further investigation and impending changes (Namwongsa, et al., 2018).

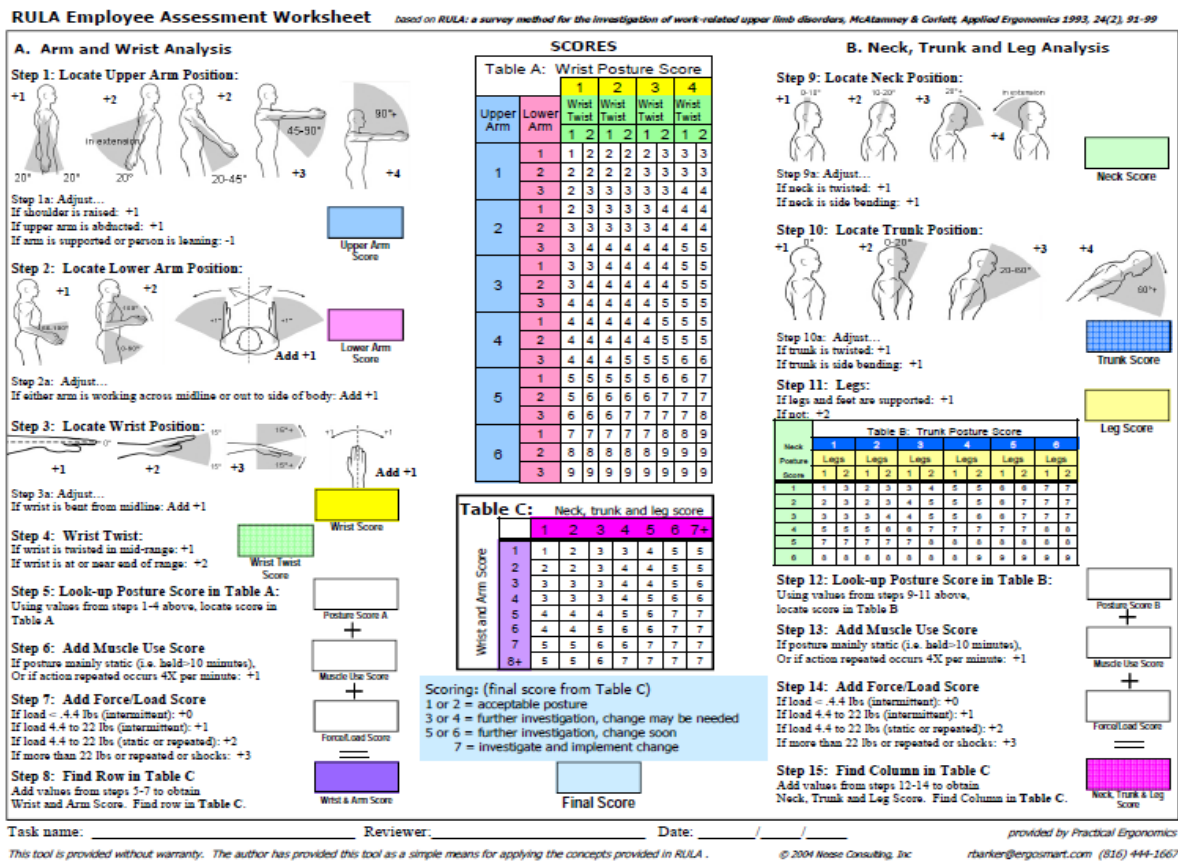


Figure 6. The Rapid Upper Limb Assessment (McAtamney & Corlett, 1993)



Work-related musculoskeletal disorders (MSDs) are a growing concern in many industries and are impairments that come from chronic pain and discomfort, which originates in nerves, tendons, muscles, and blood vessels (Paquet, Mathiassen & Dempsey, 2006). One study aimed to validate RULA as an appropriate ergonomic tool for assessing potential postural risks among the dental community. Data was collected from 104 dentists, 70 of whom were male, and not only did the findings demonstrate the RULA tool's applicability, Pearson's Chi-square test results (0.231) determined that the posture of the participants and the work-related MSDs were not associated with a significant difference. Furthermore, the study concluded that while bad posture alone does not directly lead to MSDs, it does, in combination with other various ergonomic factors faced over a long stretch of time, lead to MSDs (Golchha, et al., 2014).

A similar study composed of dental students attempted to assess the relationship between work-related MSDs and using correct sitting. Due to the need for precision and intense concentration within dentistry, work-related MSDs have been associated with the neck, upper limbs, and lower back pain. Utilizing the RULA tool on 60 dental students, participants were randomly split into a conventional seat group and a Bambach Saddle Seat (BSS) group. The Bambach Saddle Seat was devised for maintaining lumbar spine postural health, while decreasing the risk of suffering from lower back pain. The results showed that higher RULA test scores were prevalent in the dental students sitting on conventional seats (mean = 5.06 for the right side; mean = 5.03 for the left side;  $p < .05$ ) as compared to those who worked on the BSS (mean = 2.80 for the right side; mean = 2.66 for the left side,  $p < .01$ ), thus further verifying

RULA's validity and suggesting lower postural risks connected with the BSS (Gandavadi, Ramsay & Burke, 2007).

Although a reliable tool, only those who are trained on how to use will be able to properly apply RULA to assessing posture (McAtamney & Corlett, 1993). Other limitations include that it is easy to overestimate the subsequent risk, or that RULA is very much posture-based and is most applicable to jobs characterized as static with not as great of a concern on force and repetition factors (Budnick, 2013).

### **2.3.2 REBA**

Much like RULA, the REBA Tool allows for an efficient evaluation of working posture for risks of work-related MSDs (Figure 7). The development of REBA aimed to split the body into segments in relation to movement planes and provide a scoring system for muscle activity caused by static, dynamic, and rapidly changing or unstable postures (Hignett & McAtamney, 2000). To produce the final REBA score (1-15) with associated risks and action levels, three ergonomists independently coded 144 posture combinations and integrated the concepts of load, coupling, and activity scores. REBA was then further analyzed by 14 industry professionals, which included occupational therapists and ergonomists across two workshops for inter-observer reliability analysis of body part coding (Madani & Dababneh, 2016).

Observed on the REBA Employee Assessment Worksheet, Group A contains a total of 60 postural combinations for the trunk, neck and legs, whereas Group B has a total of 36 postural combinations pertaining to the upper and lower arms, and wrists. Scores from Groups A and B are then added in Table C to provide a total of 144 possible combinations. Lastly, the Table C

score is combined with an activity score, which provides a final REBA score (Hignett & McAtamney, 2000).

Several differences have been identified between REBA and RULA. Multiple studies have mentioned that REBA assessment is more applicable for whole body evaluation as well as static and dynamic work, whereas RULA is better suited for the upper body and more sedentary tasks. Additionally, REBA is more applicable to a wider range of workstations, as RULA was developed within a specific research framework and is therefore unreliable when applied to different contexts (Madani & Dababneh, 2016).

A cross-sectional study looked to evaluate work posture among 90 general dentists and specialists using the REBA tool. The excessive and repetitive nature of dentistry increases the risk of MSD development, with various studies reporting an elevated prevalence rate between 63% and 92% (Jahanimoghadam, et al., 2018). The results demonstrated that 77.8% of dentists had a final REBA score between four and seven (moderate risk level), and 12.2% of dentists had high to very high-risk levels for developing MSDs. For general practitioners and dental specialist, the mean REBA score showed moderate risk at  $5.5 \pm 1.7$  and  $5.3 \pm 2.2$  respectively. Pediatric dentists and periodontists were observed to have the highest mean REBA score at seven (Jahanimoghadam, et al., 2018).

# REBA Employee Assessment Worksheet

Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-208

### A. Neck, Trunk and Leg Analysis

**Step 1: Locate Neck Position**  
  
 Step 1a: Adjust...  
 If neck is twisted: +1  
 If neck is side bending: +1

**Step 2: Locate Trunk Position**  
  
 Step 2a: Adjust...  
 If trunk is twisted: +1  
 If trunk is side bending: +1

**Step 3: Legs**  
  
 Adjust: 30-60° +1, 60° +2

**Step 4: Look-up Posture Score in Table A**  
 Using values from steps 1-3 above, locate score in Table A

**Step 5: Add Force/Load Score**  
 If load < 11 lbs: 0  
 If load 11 to 22 lbs: +1  
 If load > 22 lbs: +2  
 Adjust: If shock or rapid build up of force: add +1

**Step 6: Score A, Find Row in Table C**  
 Add values from steps 4 & 5 to obtain Score A. Find Row in Table C.

**Scoring:**  
 1 = negligible risk  
 2 or 3 = low risk, change may be needed  
 4 to 7 = medium risk, further investigation, change soon  
 8 to 10 = high risk, investigate and implement change  
 11+ = very high risk, implement change

### B. Arm and Wrist Analysis

**Step 7: Locate Upper Arm Position:**  
  
 Step 7a: Adjust...  
 If shoulder is raised: +1  
 If upper arm is abducted: +1  
 If arm is supported or person is leaning: -1

**Step 8: Locate Lower Arm Position:**

**Step 9: Locate Wrist Position:**  
  
 Step 9a: Adjust...  
 If wrist is bent from midline or twisted: Add +1

**Step 10: Look-up Posture Score in Table B**  
 Using values from steps 7-9 above, locate score in Table B

**Step 11: Add Coupling Score**  
 Well fitting Handle and mid range power grip: good: +0  
 Acceptable but not ideal hand hold or coupling acceptable with another body part: fair: +1  
 Hand hold not acceptable but possible: poor: +2  
 No handles, awkward, unsafe with any body part: unacceptable: +3

**Step 12: Score B, Find Column in Table C**  
 Add values from steps 10 & 11 to obtain Score B. Find column in Table C and match with Score A in row from step 6 to obtain Table C Score.

**Step 13: Activity Score**  
 +1 1 or more body parts are held for longer than 1 minute (static)  
 +1 Repeated small range actions (more than 4x per minute)  
 +1 Action causes rapid large range changes in postures or unstable base

SCORES		Neck		
		1	2	3
Table A	Legs	1 2 3 4	1 2 3 4	1 2 3 4
Trunk Posture Score	1	1 2 3 4	1 2 3 4	3 3 5 6
	2	2 3 4 5	3 4 5 6	4 5 6 7
	3	2 4 5 6	4 5 6 7	5 6 7 8
	4	3 5 6 7	5 6 7 8	6 7 8 9
5	4 6 7 8	6 7 8 9	7 8 9 9	

SCORES		Lower Arm	
		1	2
Upper Arm Score	Wrist	1 2 3	1 2 3
	1	1 2 2	1 2 3
	2	1 2 3	2 3 4
	3	3 4 4	4 5 5
	4	4 5 5	5 6 7
	5	6 7 8	8 8 9

Score A (score from Table A plus force score)	Table C											
	Score B (table B value coupling score)											
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	10	10	11	11	11	11
8	8	8	8	9	10	10	10	10	11	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score

+

Activity Score

Final REBA Score

Task name: \_\_\_\_\_ Reviewer: \_\_\_\_\_ Date: \_\_\_\_/\_\_\_\_/\_\_\_\_  
 This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA. © 2000 Nasa Consulting, Inc. provided by Practical Ergonomics rbanter@ergosmart.com (816) 444-1667

**Figure 7. Rapid Entire Body Assessment (Hignett & McAtamney, 2000)**

Jobs in the farming and agriculture industry are widely recognized as some of the more dangerous fields of work, leaving farmers increasingly susceptible to developing work-related MSDs from consistent, repetitive actions over long durations of time. A second cross-sectional study utilized REBA to evaluate postural loading during the performance of various task related to dairy farming. The study's findings showed that feeding (final REBA scores between 8-11) and milking tasks (final REBA scores between 6-11) specifically put farmers at higher risk of developing MSDs (Taghavi, et al., 2017). As most tasks were associated with inexplicably high

scores, the implementation of ergonomic intervention is imperative for reducing risk of serious overuse injuries and MSDs.

### **2.3.3 Video and Computer-Based Observational Assessments**

Various ergonomic video and computer-based assessment tools are now widely available methods for evaluating posture and assessing exposure to inherent risks associated with work-related MSDs. ARBAN (Holzmann, 1982), VIRA (Persson & Kilbom, 1983), the Quick Exposure Check system (Li & Buckle, 1999), and the Ovako Working Posture Analyzing System (Karhu, Kansu & Kuorinka, 1977) are examples of tools developed for the purpose of videotaping and analyzing work postures and activities. With video-based assessments, researchers and ergonomists are able to evaluate postural data in real time, while avoiding observer bias (Li & Buckle, 1999).

ARBAN is a video-based ergonomic assessment tool, which incorporates whole body postures and loads prevalent in working environments. The ARBAN analysis process contains four steps: (1) video-recording the workplace situation; (2) Coding the posture and load situation at a number of closely spaced frames by time-sampling the video data; (3) process the computerized data; (4) evaluate the results (Holzmann, 1982). During the processing phase, the computer is able to quantify total stress on the entire body or individual body segments. The data is presented as an ergonomic stress/time curve, wherein the heavy load occurs at the peaks of the curve. These curves can be extracted for different tasks and different work situations (Holzmann, 1982).

Unlike ARBAN, VIRA is specifically an upper body posture video-based ergonomics tool. Originally developed in Sweden to evaluate neck and shoulder disorders, VIRA allows for computerized, real-time, video analysis for frequency and duration of postures as well as movements (Persson & Kilbom, 1983).

The QEC is an efficient method for identifying work-related musculoskeletal risks (Li & Buckle, 1999). The assessment aims to evaluate the back, shoulder/upper arm, wrist/hand and neck in respect to each of their postural and repetitive movements. Following the assessment, the magnitude for each parameter is classified into exposure levels and is totaled, after which the higher scores are allotted to the combination of the two-higher-level exposure of risk factors and the lower scores is given to the two lower-level exposure of risk factors (Li & Buckle, 1999). Limitations related to QEC exist as the scoring system is often hypothetical and requires further validation, and the system itself is sensitive to changes in exposure post- and pre-ergonomic intervention (Li & Buckle, 1999).

OWAS is an additional observational assessment tool meant to evaluate poor workplace posture. This simple and portable computerized system consists of an observational portion, followed by a set of criteria for the re-design of working methods and places (Karhu, Kansil & Kuorinka, 1977). OWAS is a full-body system (Kivi & Mattila, 1991) which identifies common work postures for the back (four postures), the arms (three postures), the legs (seven postures), and the weight of the load being used (three categories). Using photographic material, four operative classes were established to evaluate posture. Class one assumed normal posture with no need for specific attention; class two was met with recommendation for changes to posture during the next regular check-up; class three required postural changes in the near future; class

four required immediate consideration (Karhu, Kansu & Kuorinka, 1977). Additional video and computer-based ergonomic assessments include ROTA, TRAC, and HARBO (Li & Buckle, 1999).

#### **2.4 Pitching Mechanics Assessment Tools**

In current literature, there are only two qualitative assessment tools for pitching mechanic that exists in the sport of baseball. The purpose of the first original study was to establish the reliability and validity of a Qualitative Analysis Protocol (QAP) to find an alternative method to the industry gold standard for kinematic analysis (Nicholls et al., 2003). Data was collected with the use of a 6-camera 200 Hz Motion Analysis System and two high-speed video cameras (60 Hz) positioned to the pitcher's open side and behind the mound. The QAP identified 24 kinematic parameters throughout the pitching motion and tasked two independent raters with analysing the three fastest pitched strikes thrown by the 20 pitcher participants. Raters were provided with no prior training nor feedback. Statistical significance was reached in four QAP variables (Table 3), including elbow flexion at lead foot strike and the sequence of hip-shoulder rotation during the arm cocking phase.

**Table 3.** Kappa coefficient (k) for validity of QAP (Nicholls et al., 2003)

<i>Event</i>	<i>Variable</i>	<i>Kappa coefficients (k)</i>		
		<i>Proper-improper</i>	<i>Proper-low</i>	<i>Proper-high</i>
Foot contact	Stride length	0.45	0.51*	n/a
	Stride offset	-0.05	n/a	0.11
	Foot angle	0.15	n/a	0.63*
	Knee flexion	0.29	0.21	n/a
	Horizontal adduction	0.27	-0.22	1.00**
	Abduction	-0.1	0.44	-0.17
	External rotation	0.31	1.00**	0.16
	Elbow flexion	0.8**	1.00**	0.74**
Arm cocking	Hip/shoulder rotation	0.42*	n/a	0.52**
	Maximum elbow flexion	-0.18	0.12	-0.08
	Maximum external rotation	0.29	0.42	n/a
Ball release	Trunk flexion	0.67**	-0.12	n/a
	Lateral trunk tilt	0.31	0.39	0.19
	Knee flexion	0.13	n/a	-0.21
	Horizontal adduction	0.41*	-0.07	0.38
	Abduction	0.32	0.42	n/a
	Elbow flexion	0.21	0.19	0.44*

\*  $p < 0.05$ , \*\*  $p < 0.01$ , n/a – no qualitative result for any subject

The study ran the kappa statistic to establish intra- (Table A) and inter-rater (Table B) reliability for the protocol. The kappa coefficients ranged between 0.400 and 0.900 for intra-rater reliability and 22 of the 24 parameters were determined significant at  $P < 0.05$ . Moreover, significant agreement was deduced in eight of the 24 kinematic parameters for inter-rater reliability. The results of the study provided the necessary insight to suggest that the 3D method of kinematic analysis is not the only way to evaluate mechanics and that qualitative-



based assessment of 2D video data, while not as accurate, are viable options of analyzation (Nicholls, et al., 2003).

**Table 4.** Kappa coefficients (k) for intra- and inter-rater reliability of the QAP (Nicholls et al., 2003)

Phase	Variable	k (proper-improper)
Foot contact	Preparatory movements	0.667**
	Balance	0.794**
	Hand separation	0.857**
	Stride hip path	0.400
Stride	Stride length	0.794**
	Stride offset	0.650**
	Foot angle	0.643**
	Knee flexion	0.875**
	Horizontal adduction	0.400
	Abduction	0.794**
	External rotation	0.600**
	Elbow flexion	0.900**
	Arm cocking	Hip/shoulder rotation
Trunk arching		0.483*
Use of glove arm		0.588**
Maximum elbow flexion		0.444*
	Maximum external rotation	0.583**
Ball release	Trunk flexion	0.890**
	Lateral trunk tilt	0.890**
	Knee flexion	0.571*
	Horizontal adduction	0.771**
	Abduction	0.828**
	Elbow flexion	0.483*
Follow-through	Trunk flexion	0.600**

\* p<0.05, \*\* p<0.01

**A**

Event	Variable	Kappa coefficients (k)		
		Proper	Low	High
Windup	Preparatory movements	0.130	n/a	0.286
	Balance position	0.043	-0.023	n/a
	Hand separation	-0.170	-0.176	-0.094
	Stride hip path	0.200	n/a	0.255
Foot contact	Stride length	0.121	0.390	n/a
	Stride offset	0.340	0.588**	-0.087
Arm cocking	Foot angle	0.643**	n/a	1.000**
	Knee flexion	0.028	-0.081	0.318
	Horizontal adduction	no data available		
	Abduction	0.596**	0.565**	0.459*
	External rotation	0.474*	n/a	0.615**
	Elbow flexion	0.192	0.286	0.432
	Hip/shoulder rotation	-0.100	n/a	0.118
	Trunk arching	0.138	0.186	n/a
Ball release	Use of glove arm	0.694**	0.083	0.100
	Maximum elbow flexion	0.400	0.200	0.077
	Maximum external rotation	0.583**	0.51*	n/a
	Trunk flexion	no data available		
Follow-through	Lateral trunk tilt	0.167	0.077	0.692**
	Knee flexion	0.130	0.318	0.300
	Horizontal adduction	no data available		
	Abduction	0.468*	0.318	n/a
	Elbow flexion	no data available		
	Trunk flexion	-0.042	0.192	-0.053

\* p<0.05, \*\* p<0.01

**B**

Using the Nicholls et al., 2003 protocol as a framework, a thesis study was carried out to establish the intra- and inter-rater reliability of injury-contributing biomechanical errors (Table 5) observed in a pitching delivery for the purpose of creating a foundation for a reliable assessment tool, applicable by both coaches and sports medicine professionals in a clinical setting (Quatromoni, 2015). Pitchers were tasked to throw ten pitches, including a minimum of three strikes, while frontal and sagittal video was collected. Using video analysis, acceptable intra-rater reliability was established for all six biomechanical errors ( $K \geq 0.50$ ), whereas

acceptable inter-rater reliability was established in just three of six errors ( $K \geq 0.50$ ), including for stride foot position at lead foot strike, backward lean at lead foot strike, and contralateral lean at maximum external rotation (Quatromoni, 2015).

**Table 5.** Intra- and inter-rater reliability of six biomechanical errors (Quatromoni, 2015)

Error	Intra-Rater Reliability			Inter-Rater Reliability	
	Trial 1 vs 2	Trial 2 vs 3	Trial 1 v3	Vs. Pitcher	Vs. Clinician
Forearm Supination	0.841 (p<0.001)	0.841 (p<0.001)	0.717 (p<0.001)	-0.141 (p=0.356)	0.199 (p=0.138)
Stride Foot Position	0.643 (p<0.001)	0.583 (p=0.001)	0.693 (p<0.001)	0.577 (p <0.001)	0.580 (p<0.001)
Backward Lean	0.872 (p<0.001)	0.459 (p=0.007)	0.534 (p=0.001)	0.531 (p<0.001)	0.220 (p=0.146)
Open Shoulder	0.534 (p=0.001)	0.242 (p=0.158)	0.617 (p<0.001)	0.070 (p=0.628)	0.336 (p=0.021)
Trunk to Elbow Angle	0.619 (p<0.001)	0.469 (p=0.001)	0.686 (p<0.001)	0.469 (p=0.001)	0.353 (p=0.007)
Contralateral Trunk Lean	0.761 (p<0.001)	0.638 (p<0.001)	0.598 (p<0.001)	0.518 (p=0.001)	0.591 (p<0.001)

#### 2.4.1 Posture Assessment Software

Another important aspect of video-based posture assessments is evaluating the optimal sampling rate of video data (Table 6). One such study looked to investigate the amount of error in calculating cumulative lumbar spine kinematics using custom software (3DMatch), a posture-matching approach, compared to a 3D coordinate electromagnetic tracking system called FASTRAK™ (Sutherland, et al., 2007). Subjects were asked to wear eight FASTRAK™ sensors while performing weightlifting exercises to define eight-segment rigid link models (RLM) of the head, arms, and trunk. The subjects were recorded by four camera views at angles of 0°, 45°, 60°, and 90°. No significant difference ( $p < 0.05$ ) in relative error was found in any of the cumulative loading variables between the camera views and the 3D RLM approach (Table 8) for cumulative joint compression, anterior shear, reaction anterior shear, and extension moment.

Moreover, the relative error for compression, joint anterior shear, reaction anterior shear, and extension moment were all observed to be below 12 percent (Sutherland, et al., 2007). The research showed that 3DMatch can be an effective method for analyzing 3D movements from 2D video while using a posture-matching technique for data input to eliminate the digitization process (Sutherland, et al., 2007). The results therefore demonstrate that posture matching can provide reasonable 3D data, comparable to that of a 3D coordinate electromagnetic tracking system (Sutherland, et al., 2007). A similar study observed no significant difference ( $p = 0.7987$ ) between peak compression estimates obtained with a 3DMatch posture-matching approach relative to an EMG-assisted, dynamic 3D rigid linked segment model (Parkinson, Bezaire & Callaghan, 2011).

**Table 6.** Cumulative loading mean values for FASTRAK™ and four-camera view (Sutherland, et al., 2007).

Variable	FASTRAK™	0° view	45° view	60° view	90° view	P-value
Comp	11 142 (442)	10 481 (568)	10 500 (550)	10 694 (610)	10 834 (567)	0.136
JtAntShr	415 (24)	419 (26)	423 (28)	398 (26)	421 (27)	0.204
JtPostShr	100 (53)	153 (31)	154 (31)	156 (33)	157 (33)	0.001
RxAntShr	1102 (64)	1068 (76)	1078 (72)	1062 (73)	1103 (76)	0.670
Ext Mom	506 (28)	521 (31)	526 (28)	533 (32)	545 (31)	0.110

*Note:* Comp = cumulative joint compression; JtAntShr = cumulative joint anterior shear; JtPostShr = cumulative joint posterior shear; RxAntShr = cumulative reaction anterior shear; ExtMom = cumulative external moment.

## 2.5 Three-Dimensional Kinematics

Utilizing “gold standard” 3D motion capture, clinicians and researchers alike are able to record and analyze movement for sports performance enhancement and injury prevention. Apart from the sporting context, 3D motion capture can also be used in the entertainment industry for both film and game production. Vicon, Motion Analysis, Qualisys and OptiTrack are all various types of passive motion capture systems that support 3D motion capture. Advantages of motion capture include receiving immediate and real-time results and having the ability to recreate complex physical movement in an accurate manner. Likewise, there are definite disadvantages to using 3D motion capture, including its high cost and its limitation to being applied only inside of a laboratory setting by trained professionals. Additionally, if errors during recording trials occur, the trial must be deleted and restarted.

In baseball, specifically pitching, in which the throwing motion is a fast and dynamic yet complex movement, motion capture ultimately allows for the efficient analysis of kinematics in real-time due to its ability to collect at high sampling rates. A multitude of studies have utilized 3D motion capture in similar fashion. An Escamilla et al., 2017 study had an 18-high speed, 180 Hz camera system (XOS SportMotion Capture system) for which 25 kinematic and 7 kinetic parameters were investigated (Escamilla et al., 2017). An earlier study (Escamilla, et al. 2007) utilized a 6-high speed, 200 Hz camera system (Motion Analysis Corp) to evaluate 20 kinematic and 11 kinetic parameters. A separate study performed on a sample of 231 healthy pitchers of varying age levels utilized a 4-high speed, 200 Hz camera system (Motion Analysis Corp) to evaluate 16 kinematic and 8 kinetic parameters (Fleisig, et al., 1999). In all three cases, position-

time data was filtered with a Butterworth low-pass filter with a cut-off frequency of 13.4 Hz (Escamilla, et al. 2007; Escamilla et al., 2017; Fleisig, et al., 1999).

A 2007 study aimed to detail the biomechanics of the pitching motion by utilizing kinematic and kinetic data for the upper and lower extremities, thorax, and pelvis collected using three-dimensional motion capture analysis. In order to establish concise kinematic and kinetic parameters in adolescent pitchers, 24 participants were asked to throw maximum effort fastballs off a mound. Results showed the average of motion to be:  $63 \pm 15^\circ$  of forearm pronation/supination,  $44 \pm 14^\circ$  of wrist flexion/extension, and  $12 \pm 4^\circ$  of ulnar/radial deviation (Nissen, et al, 2007). Explosive forearm motion was observed between ball release and maximal glenohumeral internal rotation with a peak pronation velocity of  $2051 \pm 646^\circ\text{s}^{-1}$ . Internal glenohumeral rotation range of motion was  $125 \pm 13^\circ$  while the pelvis squared to the plate at  $51 \pm 10\%$  and the thorax at  $59 \pm 7\%$  of the pitch cycle (Nissen, et al., 2007).

### **2.5.1 Other Methods of Kinematic Analysis**

Although video-based motion capture can resolve ball speed, it heavily relies on the positional data obtained from high-speed cameras and therefore fails to provide the necessary information regarding the angular velocity and velocity of the ball over time (McGinnis & Perkins, 2012). A study aimed to address the limitations of motion capture by incorporating wireless inertial measurement units (IMUs) in both baseballs and softballs. An IMU can be a miniature form of non-intrusive sensor technology for measuring kinematics in real time on the field of play. A single baseball and softball pitcher were then asked to perform five throws, and the work demonstrated that sensor technology can in fact provide the magnitude and direction

of the ball's velocity at release point to within 4.6% of measurements carried out by standard motion capture (McGinnis & Perkins, 2012).

Wearable motion analysis systems (WMAS) have been developed for the purpose of analyzing human movement outside of a laboratory setting, especially pertaining to potential concussion diagnosis. Today, most WMAS consists of inertial measurement units (IMUs) that are attached to various body segments (i.e. the sternum, waist, left and right thigh, and left and right shank). Each IMU is small, portable, and holds a long-lasting battery with large storage capacity, therefore making it useful for outdoor situations (Martori, 2013). In order to evaluate joint forces and moments in nine joints (cervical, thoracic, lumbar, right shoulder, right elbow, right wrist, right hip, right knee, and right ankle) during gait, one study incorporated an IMU system and compared its data to that of a more conventional (motion capture) system (Khurelbaatar, et al., 2015). There was a strong correlation observed in terms of joint forces between the WMAS and the conventional system with small normalized root mean squared error in all noted joints ( $r = 0.71-0.99$ ; normalized root mean squared error = 5.5-6.2%). Significantly high correlations in the lower extremities ( $r = 0.99$ ), the trunk ( $r = 0.80-0.81$ ), and the upper extremity ( $r = 0.71-0.79$ ) were noted. Outside of the shoulder ( $r = 0.49$ ), joint moments showed good agreement with strong correlation ( $r = 0.70-0.98$ ) as well (Khurelbaatar, et al., 2015).

Despite the precision and popularity of reflective marker motion capture, this method of kinematic analysis comes with several limitations, most notably the markers themselves can affect the subject's movement and they require a controlled laboratory setting. A markerless set up has been under development for the purpose of eliminating such restrictions, but its

accuracy has been questionable to this point. Driveline Baseball have been a large proponent for marker-based systems, citing the typical mean errors in reconstruction to be approximately 0.8 mm, whereas, markerless set-up typically lacks the validation necessary for conclusive analysis. To this point, markerless capture cannot track rotation about an axis nor can it provide accurate readings for valgus carrying angles and other deformations (Driveline Baseball, 2018). A controlled lab study attempted to validate markerless motion capture and although the processing requires more time, it's tracking ability was shown to be rather accurate; mean errors  $3.9^{\circ}$  ( $\pm 4.1^{\circ}$ ) and  $2.7^{\circ}$  ( $\pm 4.7^{\circ}$ ) for hip and knee internal-external rotation (Corazza, et al., 2006).

3D kinematics with electrogoniometers (EGMs) is another method of performing biomechanical analysis. Ideal for measuring dynamic movements, EGMs change voltage with changes in joint angles, after which there is a calibration factor that relates a change in voltage to an angle. A study aimed at investigating the concurrent validity of utilizing EGM and the Vicon motion analysis system to measure knee angular velocity in stroke subjects determined that the intraclass correlation coefficient (ICC) value (lower 95% confidence interval) for both Vicon and EGM was 0.90 (0.87) at peak flexion angular velocity and 0.92 (0.89) at peak extension angular velocity (Pomeroy, Evans & Richards, 2006). The limits of agreement were observed to be wide despite the high ICC values;  $-50.64$  to  $80.28^{\circ}/\text{second}$  for peak flexion angular velocity and  $-30.59$  to  $86.27^{\circ}/\text{second}$  for peak extension angular velocity. The high level of disagreement is also evident by the coefficient of variation of the method error values of 10.07% for peak flexion angular velocity and 10.79% for peak extension angular velocity (Pomeroy, Evans & Richards, 2006). Despite excellent ICC values, the wide limits of agreement

would suggest that it is improper to use EGM and the Vicon system interchangeably to measure knee angular velocity in stroke subjects.

Outside of ‘gold standard’ 3D kinematic analysis, 2D analysis systems are also available. One study aimed to test and compare the validity and reliability of different kinematic methods during a simple biking task. For the purposes of the study, 11 cyclists performed five three-minute cycling trials, three of which were at different seat heights (25°, 30°, and 35° knee angle at bottom dead center) and two were at the subject’s preferred seat height. Thirteen motion capture cameras (3D), a high-speed camera (2D), and an EGM were utilized to measure the knee angle of each cyclist during all five trials of pedaling. Results deduced that the 2D analysis and the EGM significantly underestimated knee angle ( $P = 0.00$ ;  $\eta^2 = 0.73$ ) as compared to the ‘gold standard’ 3D system (Fonda, Sarabon & Li, 2014). Although each of the three dynamic methods achieved a good intra-session reliability (Table 7), adding a 2.2° correction factor for 2D kinematics would provide higher precision (Fonda, Sarabon & Li, 2014). Other 2D observational methods include accelerometers and goniometers.

**Table 7.** Intra-session reliability for three kinematic methods (Fonda, Sarabon & Li, 2014)

Method	Trial 1 (°)	Trial 2 (°)	Difference ± SD	Absolute limits	<i>P</i>
2D camera	42.1 ± 7.4	43.8 ± 7.5	-1.7 ± 4.3	-1.7 ± 8.4	0.21
3D Vicon	42.9 ± 8.5	43.9 ± 6.7	-1.1 ± 4.1	-1.1 ± 8.0	0.41
Electrogoniometer	32.3 ± 22.3	32.0 ± 20.3	0.3 ± 2.5	0.3 ± 5.0	0.73



## 2.6 Financial Implications and Market Needs

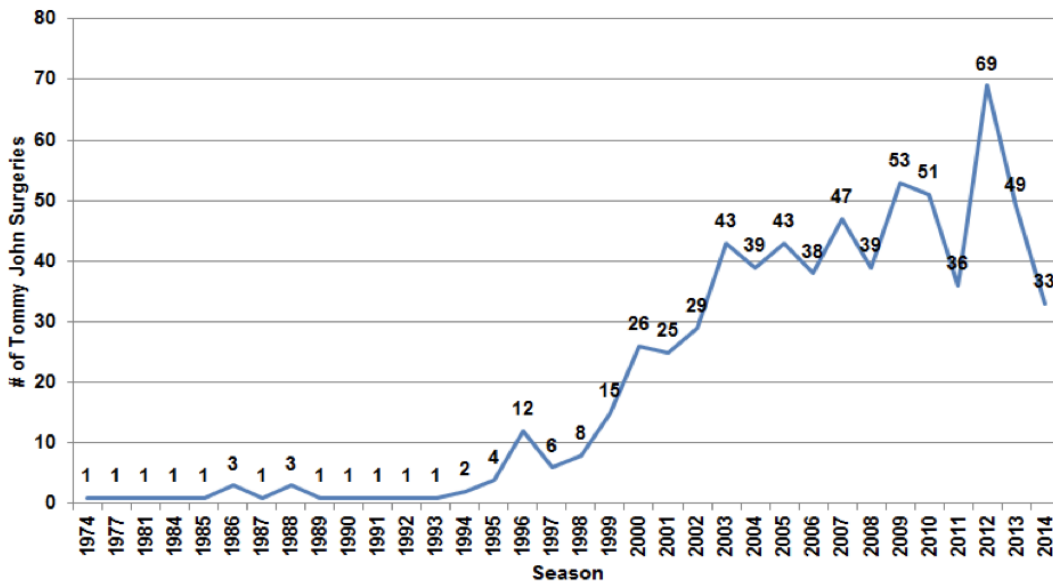
### 2.6.1 Professional Level

As of the start of the 2019 MLB season, there are five starting pitchers who earn upwards of \$30-million annually with another ten who are slated to make at least \$20-million this season. Relief pitchers, who more often than not fail to amass even half the amount of innings that a starting pitcher works in a season also cost a premium fee in today's game. Aroldis Chapman of the New York Yankees, Wade Davis of the Colorado Rockies, and Kenley Jansen all make close to \$20-million dollars annually on their current contracts. Entering the regular season, the Chicago Cubs were projected to have the highest team payroll in the entire league at \$211.5-million dollars; a combined \$76.5-million or 36.2% of the total salary accounts for starters Yu Darvish, Jon Lester, Cole Hamels and reliever Brandon Morrow (Spotrac, 2019). With all of that in mind, the importance of pitching in professional baseball cannot be disputed. In fact, ESPN columnist Jeff Passan stated in his book, *The Arm: Inside the Billion-Dollar Mystery of the Most Valuable Commodity in Sports*, that pitching on the Major League level has cost all 30 teams a combined \$1.5-billion during the 2016 offseason (Passan, 2016). The high costs allotted towards pitching is an expensive risk that professional teams must take in order to compete for a World Series championship. If a pitcher does get injured, the team is still obligated to pay the player's salary despite the pitcher's inability to continue performing. Therefore, it is imperative that teams track their pitcher's fatigue levels throughout a season and maintain the arm health of their lucrative investments (Figure 8).

Moreover, if a team's star pitcher is unable to perform on their scheduled start date, the organization loses in terms of fan attendance. In 2014, the Miami Marlins drew an average of

28,923 fans on days in which Jose Fernandez started, but only 21,437 on days in which he was unavailable (Campbell, 2014).

The market needs a streamline product, which is accessible to both MLB coaches and scouts in order to analyze pitching biomechanics during a pitcher’s delivery in real-time. It is important for MLB teams to have access to a tool that is easy to use and acts as a preventative or forecasting measure of a potential UCL tear.



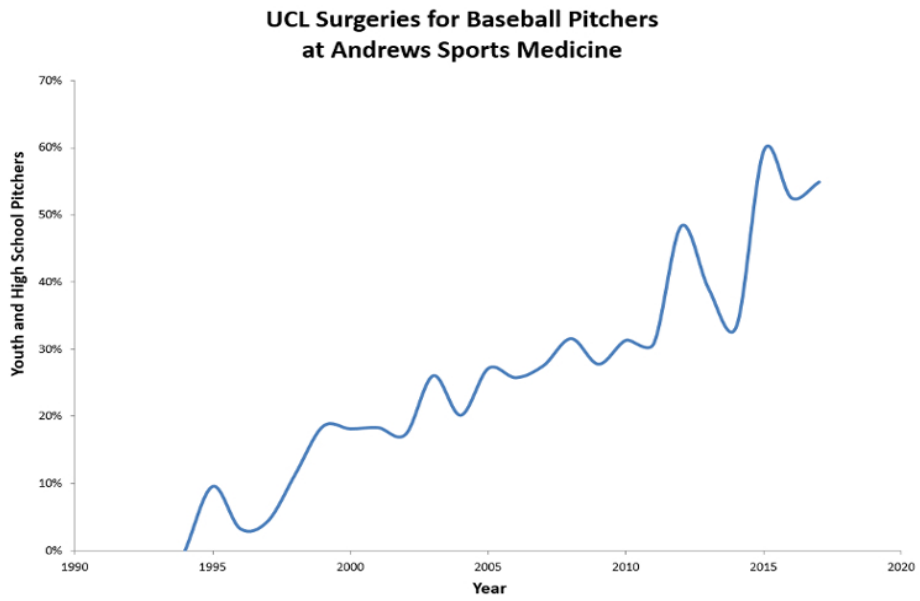
**Figure 8.** Tommy John Surgery cases year-by-year across all levels of professional baseball (<https://www.sporttechie.com/the-evolutionary-science-of-tommy-john-surgery/>)

### 2.6.2 Amateur Level

The most alarming increase in elbow injuries has been observed on the amateur level, particularly in youth and high school pitchers (Petty, et al., 2004). Approximately 5 million children ages six to 17 play organized baseball across the United States and roughly half of

those pitchers report experiencing elbow or shoulder pain at some point during the season (Yang, et al., 2014). Since 1994, the rates of TJS have significantly increased (Figure 9) and the American Sports Medicine Institute predicts a continued rise amongst youth and high school pitchers. Excessive amounts of competitive year-long throwing, high ball velocity, increased usage of breaking balls, and inadequate warmups and recovery methods have all been shown to be factors contributing to the consistent rise in UCL Injuries in both youth and high school level pitchers (Petty, et al., 2004).

The financial side of TJS is another important aspect that must be taken into account by the pitchers' parents and guardians. The approximate cost of elbow reconstructive surgery in the United States is upwards of \$15,000, after which the cost for at least 10 months of rehab and physiotherapy is an estimated \$20,000 (Gossett, 2012). In Canada, amateur athletes with access to health insurance will not be subjected to any costs. At the same time, undergoing surgery and undertaking the lengthy rehabilitation process would not only force pitchers to stay off the field for an extended period of time, but it could also impact their opportunity to get recruited by Canadian Universities or NCAA schools. It is therefore vital that coaches and even parents have access to a reliable tool which can analyze pitching kinematics and promote proper and healthy pitching development on the grass-roots level.



**Figure 9.** UCL Reconstruction Surgery rates increasing on youth and high school levels ([http://www.asmi.org/images/YouthHighSchoolUCL\\_2018.jpg](http://www.asmi.org/images/YouthHighSchoolUCL_2018.jpg))

## **Chapter 3: Methods**

### **3.1 Overview**

Data collection for this thesis was two-fold. In the first phase, 11 right-handed adult pitchers were recruited to throw off an indoor mound inside of the Biomechanics lab at Brock University. In the second phase of the study, six pitching coaches, scouts, and baseball analysts were recruited to analyze the pitching kinematics of the highest velocity fastball of each pitcher by using the thesis developed pitching mechanics tool. The evaluators' results were then compared to the gold standard 3D-motion capture data to establish validity of the developed pitching mechanics tool.

#### **3.1.1 Participants**

11 right-handed Ontario University Athletics (OUA) baseball pitchers, aged 18 and older, with no baseball-related injuries in the past year were recruited. All baseball pitchers were either undergraduate or graduate students recruited from various universities and colleges in Ontario. Pitchers were excluded if they had any reduced upper and/or lower extremity mobility. Pitchers came to the Neuromechanics and Ergonomics Lab at Brock University to complete the experiment.

### 3.1.2 Experimental Setup

Upon arrival, pitchers read an informed consent, and once all of their questions were adequately answered, they were required to sign the consent form. Additionally, pitchers were familiarized with the instrumentation and data collection that was incorporated throughout the experiment, including 3D kinematic.

Three-dimensional full body kinematics were measured using a 10-camera Vicon motion capture System (Vicon, UK) which surrounded an indoor pitching mound. The origin was set at the top of the mound on the right end of the force plate (facing the net) and the laboratory axis system was established; medial/lateral in the X-axis, posterior/anterior in the Y-axis, and rotational in the Z-axis. The sample rate was set at 240 Hz. Using double-sided and Hypafix tape, individual markers as well as custom-molded rigid bodies consisting of light weight reflective markers were placed over anatomical landmarks which included (Figure 10):

- Head (8): right and left front of head, right and left back of head, right and left top of head, right and left ear
- Upper Body Markers (20): bilaterally over the radial and ulnar styloids, lateral and medial humeral epicondyles, lateral superior tip of the acromions, iliac crests, anterior superior iliac spines, and the posterior superior iliac spines. Also over the xiphoid process, suprasternal notch, T10, and C7
- Upper Body Rigid Bodies (5): bilaterally over the forearms and upper arm (mid-segmental regions), as well as on the chest

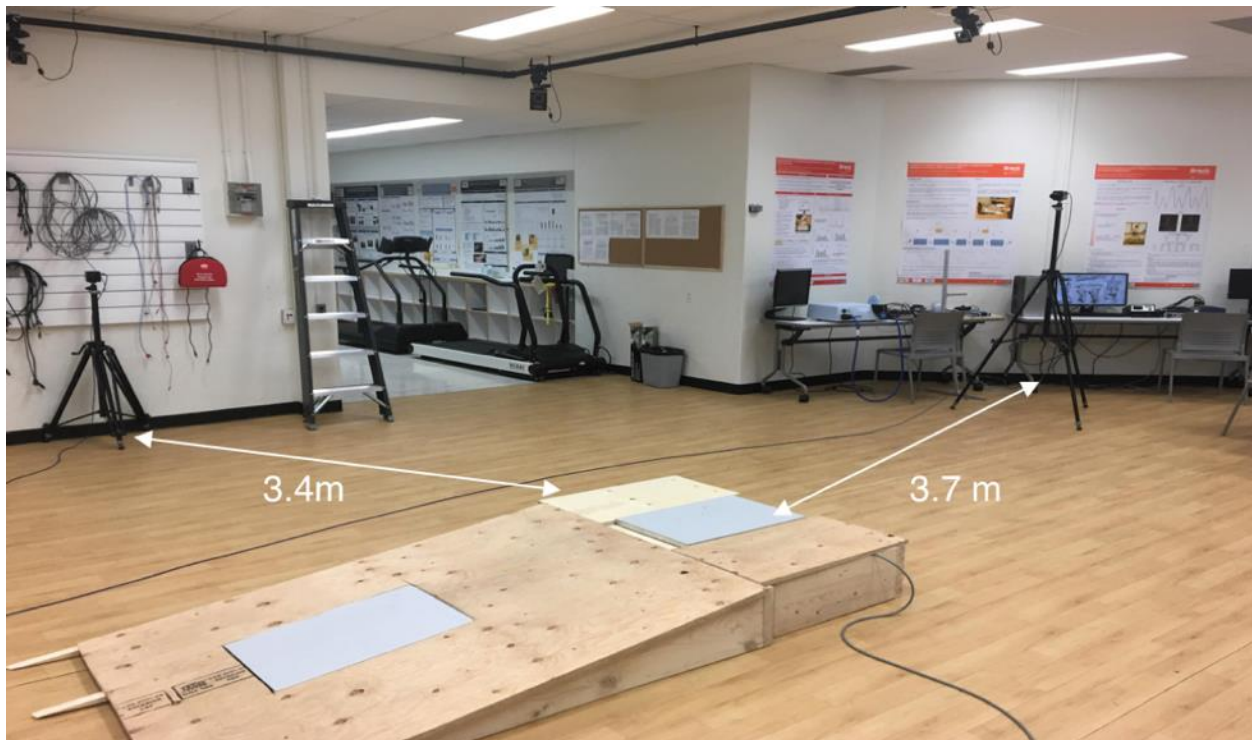
- Lower Body Markers (14): bilaterally at the lateral and medial malleoli, the lateral and medial femoral epicondyle, the greater femoral trochanters, the heels, and the toes.
- Lower Body Rigid Bodies (4): bilaterally over the thighs and tibia (mid-segmental regions)

The rigid bodies were used to track segments during experimental testing and were secured to the participant using doubled-sided tape at the mid-segmental regions. A static and motion calibration was carried out to determine the fixed spatial relationship between the rigid bodies and the calibration markers over the anatomical landmarks.



**Figure 10.** Reflective marker placement for 3D motion capture

Two high-speed video cameras (Vicon Vue) captured the pitching motion (1920 \* 1080 resolution, 120 frames per minute). The first camera was positioned orthogonally to the pitcher, to capture the front side of the body (on the right of the mound for right-handed pitchers, at 3.4m distance from the mound). The second camera was positioned at a 20-degree angle with respect to the mound (3.7m behind the mound), behind the pitcher (Figure 11). This simulated the outfield camera angle often seen during major league baseball broadcasts. A Pocket radar was used to measure ball velocity, which was recorded as the ball left the pitcher's hand.



**Figure 11.** Position of the video cameras with respect to the mound during data collection

Pitchers threw off of a custom-made pitching mound (0.2m height at its peak with a 7° downhill slope). The slope was 1.9m in length and 1.2m in width. The pitching mound had two



imbedded 60x40cm force plates (BTS P6000, Italy), one at the top of the mound, in place of the traditional pitching rubber and a second force plate on the slope. The sample rate of the two force plates was 2160 Hz. The force plates were zeroed following each pitch and the axis system matched that of the lab origin.

### **3.1.3 Experimental Trials**

#### Part 1: Laboratory data collection

Once all equipment was secured to the participant and the motion capture volume calibrated, each pitcher was given an unlimited amount of time for stretching, warm-up throwing, pitching off the indoor pitching mound and any other type of preparation desired. Pitchers were instructed to prepare as if they were going to pitch in a game.

The data collection protocol consisted of a 30-pitch throwing session. Pitchers threw both fastballs and curveballs, in blocks of 5 pitches (5 fastballs, followed by 5 curveballs). Each pitch was thrown off the mound and into a net (velocities were recorded for each pitch), approximately 15 meters away from the starting location. Pitchers could take as much time between pitches as they required to prevent any fatigue from accumulating.

The pitching session ended when a pitcher reached 30 pitches, or if they felt they could not continue because of fatigue or discomfort. Kinematics and ground reaction forces were collected for each pitch.

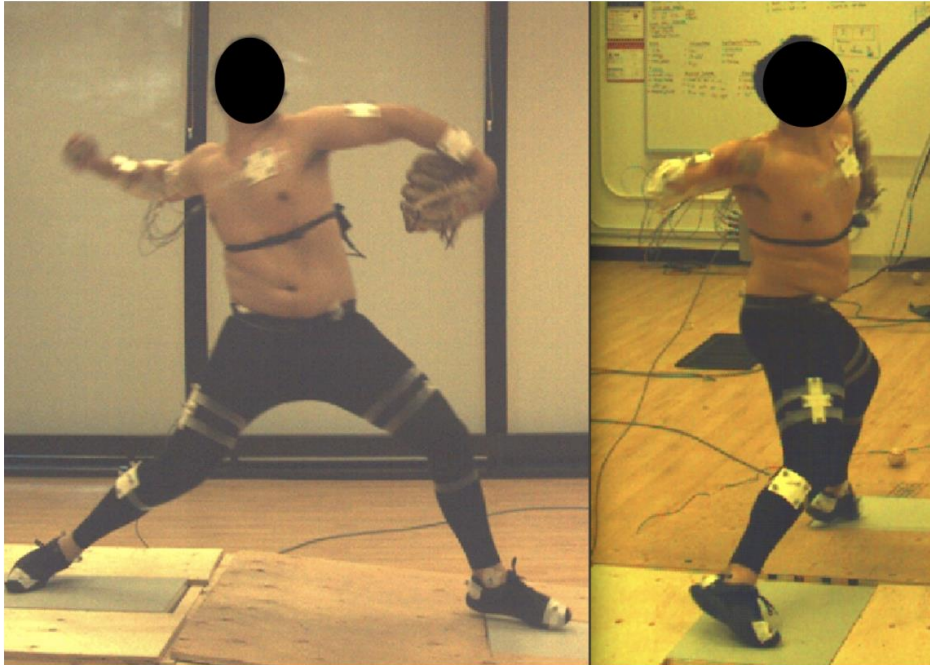
#### Part 2: Mechanics evaluation by Evaluators

The kinematic data from each pitcher was analyzed (see data analysis section), and the highest velocity fastball thrown for each pitcher was selected for further analysis. Video of each pitcher was processed for this pitch, and using the force plate data, the frame of the first instance of foot strike was selected for further analysis.

Next, six pitching coaches, scouts, and/or baseball analysts with at least 5 years of experience working with adult baseball pitchers were recruited to complete the Pitching Mechanics Tool in Google Forms. The evaluators used two different camera images (rear and open side) which was provided for each of the 11 pitchers at lead foot strike. The evaluators were responsible for selecting the most representative posture of each joint (Figure 12), for each pitcher (the developed PMT – details below). For each pitcher, evaluators had access to 16 kinematic parameters and selected the most appropriate posture that best represented the posture. Evaluators first assessed two trial pitchers for whom they were given immediate feedback. Once the feedback was carefully reviewed, the evaluators then performed three more blocks of assessments on the remaining nine pitchers. The instructions given to the pitching coaches were as follows:

1. The pitching mechanics tool will evaluate a pitcher's posture at the instance of lead foot strike as identified by the force plate data.
2. Each evaluator will be provided with a participant ID.
3. At this point, check off the postures which are appropriate in the tool. The experimenter cannot give you any feedback on your answers past the first two trial pitchers.
4. Take as much time as you want. When you are finished, notify the experimenter.

The procedure from the first day was repeated twice. This included the evaluation of two trial pitchers and immediate feedback on the performance. The time between day 1, 2, and 3 was a minimum of 2 days and a maximum of 5 days.

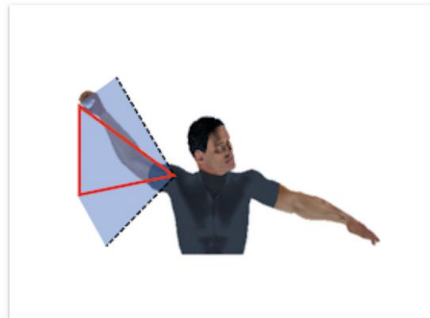


Shoulder Abduction

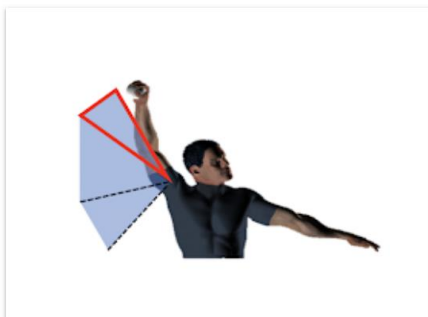
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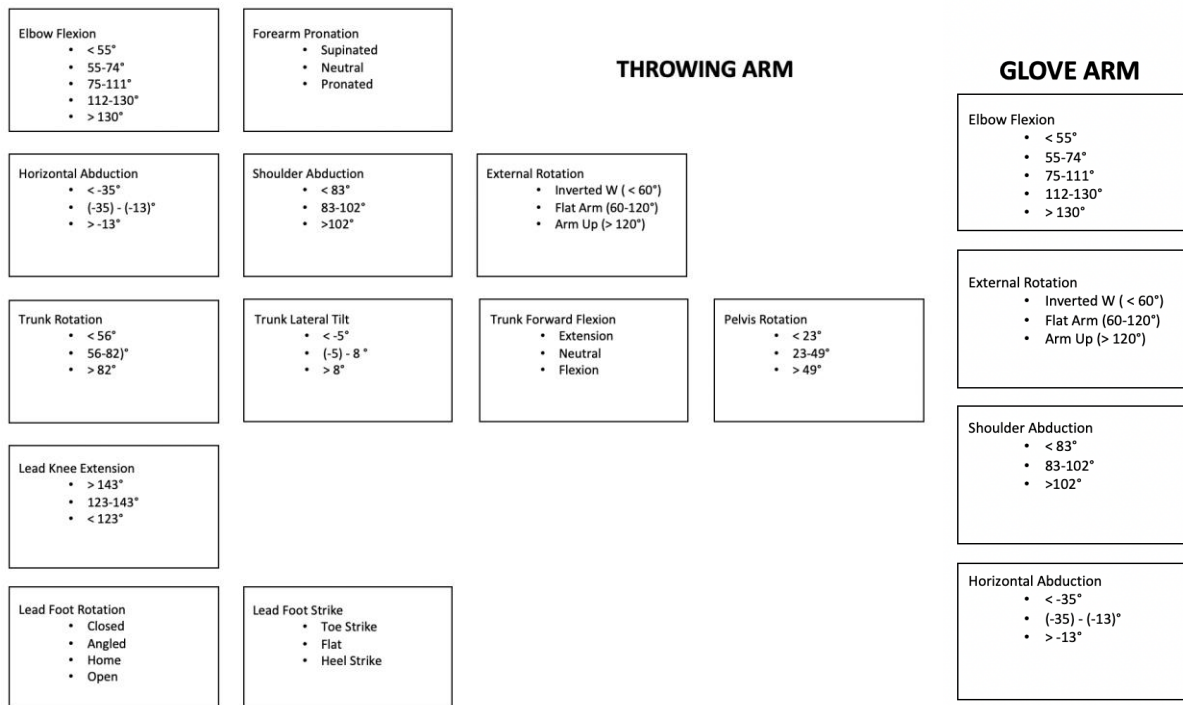


>102°

**Figure 12.** Example images used in the PMT provided to evaluators in Google Forms

### 3.2 Pitching Mechanics Tool

The Pitching Mechanics Tools (PMT) was designed to evaluate full-body posture at the instant of lead foot strike (Figure 13). The tool consisted of static images of the forearm, upper arm, trunk, pelvis, and knee, foot position during the lead foot strike of the baseball pitching motion.



**Figure 13.** Pitching Mechanics Tool

Posture ranges were binned into appropriate degree increments. The initial bin for each body segment was established using scientific literature, after which one standard deviations from the mean was used to create the remaining bins for each parameter. In terms of elbow flexion, two standard deviations from the mean were used to create the bins for the parameter in both the throwing arm and the glove arm. The evaluators were tasked with determining the

posture bin category of the pitcher that most closely represented the still images provided. For the sake of this experiment, postural bins in this tool are with reference to right handed pitchers.

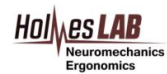
The thesis developed pitching mechanics tool takes a similar form of other notable ergonomic assessment tools such as the RULA and REBA tool (Figure 14). Foot strike was assessed based on how the pitcher landed down the slope of the pitching mound with the foot posture as three categories (*heel up, flat, or toe up*). Upon lead foot strike, the lead foot may also be rotated, and four categories were developed (foot points towards *home, is angled, open or closed off* towards third base in right-handed pitchers). 180° of rotation denoted the foot pointing directly towards home plate, whereas 90° of rotation occurred when the foot was closed off and positioned directly towards third base. Excessive internal rotation of the foot (perpendicular to the direction to the mound) would force the arm to be ahead of shoulder rotation, forcing the right-handed pitcher to throw across their body in an effort to throw strikes (Calabrese, 2013). Three bins for knee extension were created for the pitching mechanics tool:  $<123^\circ$ ,  $123-143^\circ$ , and  $>143^\circ$ . A fully extended knee represents 180° of extension.

Three separate parameters were analyzed at the trunk and one parameter was assessed at the pelvis. Three bins were created for trunk rotation ( $<56^\circ$ ,  $56-82^\circ$ , and  $>82^\circ$ ), trunk lateral tilt ( $<-5^\circ$ ,  $(-5)-8^\circ$ , and  $>8^\circ$ ), trunk forward flexion (*extension, neutral, and flexion*), and pelvis rotation ( $<23^\circ$ ,  $23-49^\circ$ , and  $>49^\circ$ ). The trunk rotates towards home plate at 0° of rotation, whereas 90° of rotation occurs when the trunk rotates to face third base at lead foot strike. The trunk tilted positively denotes lateral flexion towards the mound, while the trunk tilted

negatively denotes medial flexion away from the mound. Similar to trunk rotation, the pelvis at set position demonstrated 0° of rotation, but 90° of pelvis rotation occurs when the pelvis rotates to face home plate (View Appendix H for printable version of PMT).

**Pitching Mechanics Tool**

Pitcher Name: \_\_\_\_\_  
 Evaluator: \_\_\_\_\_  
 Date: \_\_\_\_\_



**Instructions:** The PMT is designed to evaluation pitcher kinematics at the instance of front foot strike. Record video of a pitcher throwing off of a mound, preferably at greater than 60 frames per second (for best results). Freeze the video at the moment any contact is made between the front foot, and the ground, and estimate the range for each of the 16 parameters contained within this tool.

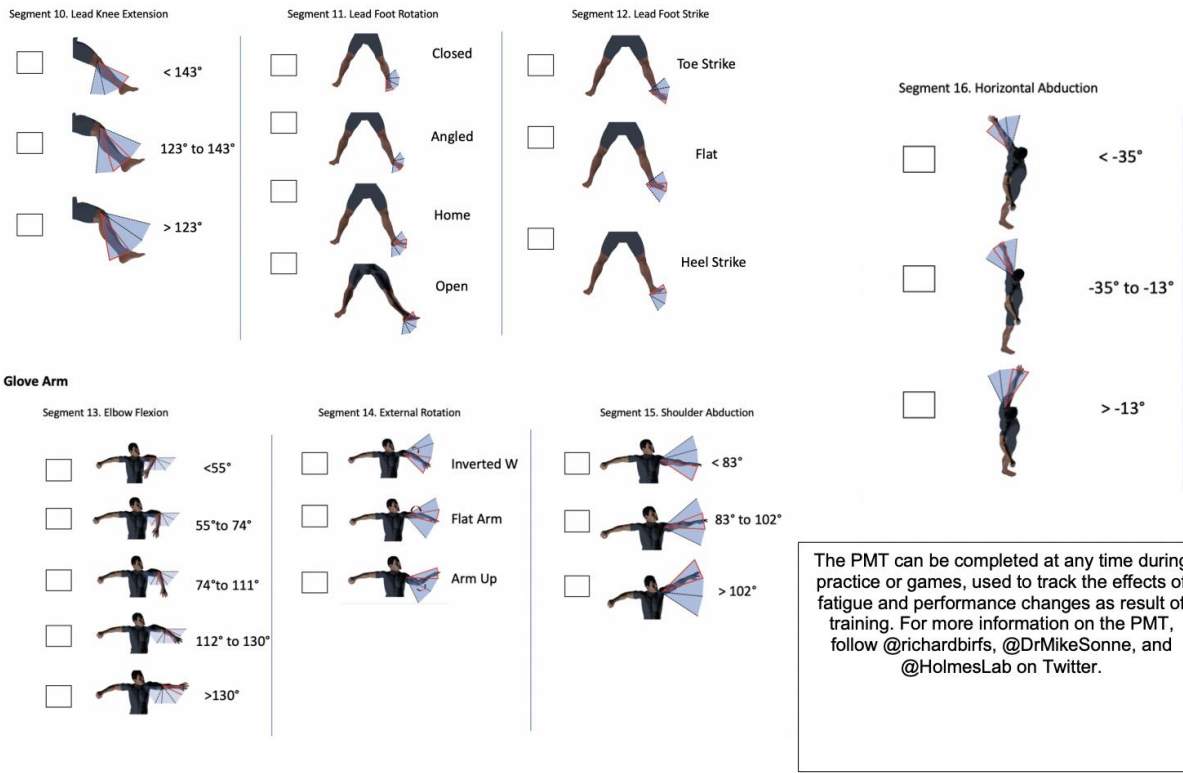
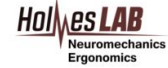
**Throwing Arm**

Segment 1. Elbow Flexion	Segment 2. Forearm Pronation	Segment 3. Horizontal Abduction	Segment 4. Shoulder Abduction	Segment 5. External Rotation
<input type="checkbox"/> <55°	<input type="checkbox"/> Supinated	<input type="checkbox"/> < -35°	<input type="checkbox"/> < 83°	<input type="checkbox"/> Inverted W
<input type="checkbox"/> 55° to 74°	<input type="checkbox"/> Neutral	<input type="checkbox"/> -35° to -13°	<input type="checkbox"/> 83° to 102°	<input type="checkbox"/> Neutral
<input type="checkbox"/> 74° to 111°	<input type="checkbox"/> Pronated	<input type="checkbox"/> > 13°	<input type="checkbox"/> > 102°	<input type="checkbox"/> Arm Up
<input type="checkbox"/> 112° to 130°				
<input type="checkbox"/> >130°				
Segment 6. Trunk Rotation	Segment 7. Trunk Lateral Tilt	Segment 8. Trunk Forward Flexion	Segment 9. Pelvis Rotation	
<input type="checkbox"/> < 56°	<input type="checkbox"/> < -5°	<input type="checkbox"/> Extension	<input type="checkbox"/> < 23°	
<input type="checkbox"/> 56° to 82°	<input type="checkbox"/> -5° to 8°	<input type="checkbox"/> Neutral	<input type="checkbox"/> 23° to 49°	
<input type="checkbox"/> > 82°	<input type="checkbox"/> > 8°	<input type="checkbox"/> Flexion	<input type="checkbox"/> > 49°	

This tool was produced and is owned by Richard Birfer, Michael Sonne, and Michael Holmes. Use of the PMT is freely acceptable, but please cite Birfer, Holmes and Sonne, 2019, when referring to the tool. For additional information on the PMT, please contact Michael Sonne – [michaelsonne@gmail.com](mailto:michaelsonne@gmail.com), or @DrMikeSonne on Twitter.

**Pitching Mechanics Tool**

Pitcher Name: \_\_\_\_\_  
 Evaluator: \_\_\_\_\_  
 Date: \_\_\_\_\_



This tool was produced and is owned by Richard Birfer, Michael Sonne, and Michael Holmes. Use of the PMT is freely acceptable, but please cite Birfer, Holmes and Sonne, 2019, when referring to the tool. For additional information on the PMT, please contact Michael Sonne – [michaelsonne@gmail.com](mailto:michaelsonne@gmail.com), or @DrMikeSonne on Twitter.

**Figure 14.** Pitching Mechanics Tool with all bins for each of the 16 kinematic parameters

External rotation occurs at the shoulder, causing the elbow to rotate about the humerus laterally. Within the PMT, three bins were defined for humeral rotation with 0° signifying the hand point straight down and 180° signifying the hand pointing straight up. Therefore, based on the rotation of the humerus, the *Inverted W* (Douoguih, Dolce & Lincoln, 2015) position can be defined as < 60°, the flat arm position can be defined as 60-120°, and >120° can be described as the arm up position. Shoulder abduction and horizontal abduction at lead foot strike were analyzed as well. Three bins were created for shoulder abduction (<83°, 83-102°, and >102°), and three bins were created for horizontal abduction (<-35°, (-35) -(-13)°, >-13°). In



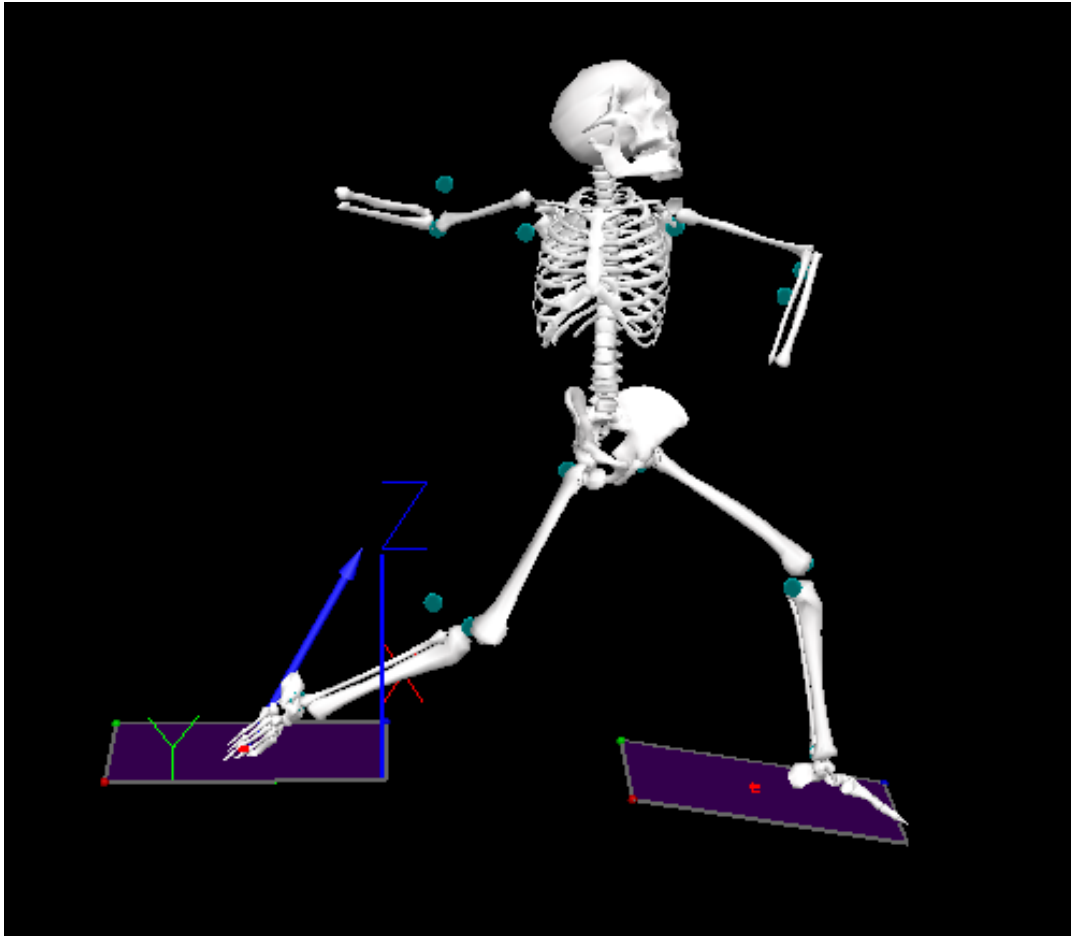
terms of shoulder abduction,  $0^\circ$  of abduction denotes to the arm being positioned straight down,  $90^\circ$  of abduction denotes to the upper arm being positioned perpendicularly to the trunk, and  $180^\circ$  of abduction denotes to the arm pointing upwards. The shoulder was horizontally abducted at  $0^\circ$  when the upper arm was lateral and perpendicular to the trunk.  $90^\circ$  of horizontal abduction occurs when the arm is held perpendicularly to the trunk directly anterior (medial) to the body, whereas  $-90^\circ$  of horizontal abduction occurs when the arm is held perpendicularly to the trunk directly posterior (medial) to the body.

The PMT defined three separate ranges for forearm rotation with supination as anything less than  $(-60^\circ)$ , neutral as between  $(-60)$  and  $60^\circ$ , and pronation as anything  $> 60^\circ$ .  $-90^\circ$  of pronation denotes to the ball facing directly towards the mound, whereas at  $0^\circ$ , the ball is facing towards third base. At  $90^\circ$  of supination, the ball is facing directly towards second base. Lastly, the tool also created five different bins for elbow flexion in  $<55^\circ$ ,  $55-74^\circ$ ,  $74-111^\circ$ ,  $112-130^\circ$ , and  $>130^\circ$ . The same bins were utilized in the glove arm for elbow flexion, external rotation, shoulder abduction, and horizontal abduction. Refer to Appendix G for the complete Pitching Mechanics Tool Google Form.

### **3.3 Data Analysis**

At the instant of lead foot strike as identified by force plate data (Figure 15), the following kinematic parameters were measured: elbow flexion (Figure 16), forearm pronation, shoulder external rotation, shoulder abduction, shoulder horizontal abduction, trunk rotation

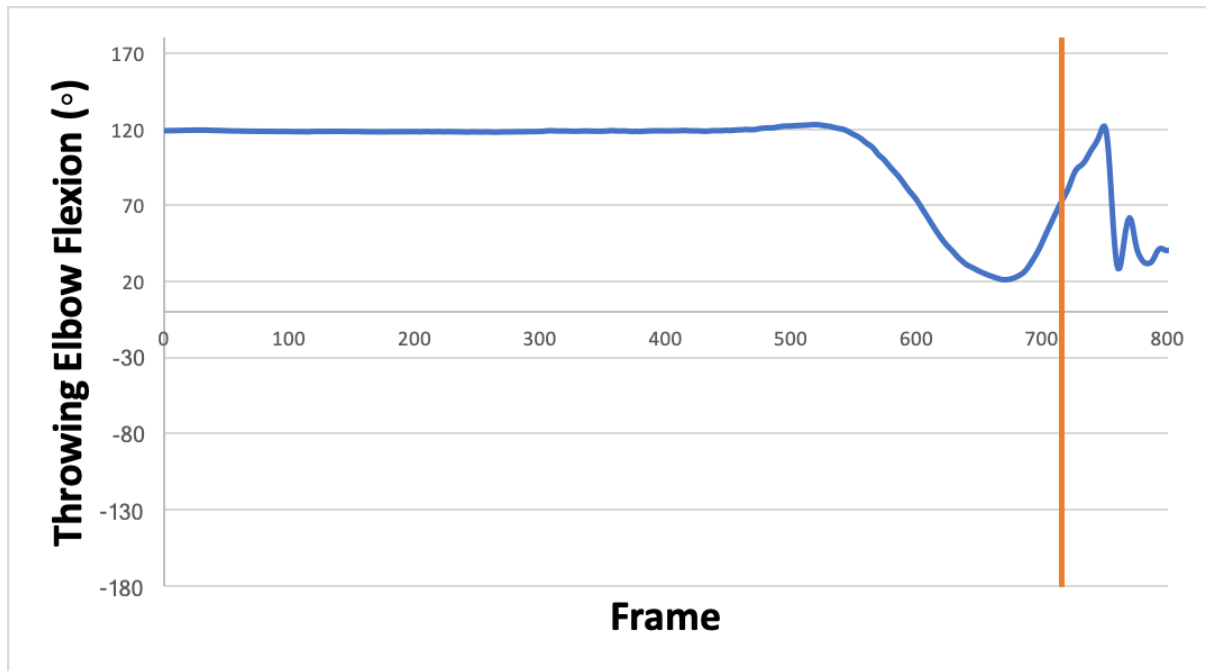
(with respect to pelvis), trunk lateral tilt, trunk forward flexion, pelvis rotation, lead knee extension angle, and lead foot rotation (Refer to Appendix G).



**Figure 15.** Biomechanical model developed in Visual 3D, lead foot strike for one representative participant is shown.

The joint angles were calculated for the highest velocity fastball thrown by each pitcher. All kinematic data was labelled in Vicon Nexus (2.7.1) and gap-filled (cyclic and spline fill). A spline fill was used when certain frames had no gaps on either side of a gap, while a cyclic fill was utilized to fill gaps of repetitive motions. Kinematic data was exported as c3d files and a linked segment biomechanical model was developed in Visual 3D (c-motion 2017, x64

Professional v6.01.09). Kinematics were low-pass Butterworth filtered with a 20 Hz cut-off (similar to Boddy et al., 2019). Joint angles were calculated for each of the 16 kinematic parameters that appear in the PMT and the local coordinate systems were in line with ISB recommendations (Wu, et al., 2004).



**Figure 16.** Elbow flexion angle generated using Visual 3D

The elbow joint was calculated using the forearm relative to the upper arm, in which the X-axis corresponded to elbow flexion and the Z-axis corresponded to forearm pronation (Table 8). Elbow flexion was measured similarly in the glove arm. Shoulder joint kinematics were calculated as the upper arm relative to the trunk, where the Z-Axis was external rotation and the Y-axis was horizontal abduction. Forearm relative to the lab provided a measure of shoulder abduction in the Z-Axis. Trunk rotation was calculated as the trunk relative to the laboratory, and the Z-Axis corresponded to trunk rotation, the Y-Axis forward flexion, and the X-Axis trunk

lateral tilt. Pelvic rotation was calculated using pelvis relative to the lab in the Z-Axis. The glove arm kinematics were calculated using the same methodology. For the lower body, shank relative to the thigh was used to calculate lead knee extension in the X-Axis and the foot relative to the lab measured lead foot rotation in the Z-Axis.

**Table 8.** Explanation of joint angles measured at lead foot strike in Visual3D. Joint angles measured in accordance with ISB recommendations (Wu, et al., 2004)

Parameter	Angle	Axis
Elbow flexion (throwing arm/glove arm)	Forearm relative to the upper arm	<i>x</i>
Forearm pronation	Forearm relative to upper arm	<i>z</i>
Horizontal abduction (throwing arm/glove arm)	Upper arm relative to trunk	<i>y</i>
Shoulder abduction (throwing arm/glove arm)	Forearm relative to lab	<i>z</i>
External rotation (throwing arm/glove arm)	Upper arm relative to trunk	<i>z</i>
Trunk rotation	Trunk relative to lab	<i>z</i>
Trunk forward flexion	Trunk relative to lab	<i>x</i>
Trunk lateral tilt	Trunk relative to lab	<i>y</i>
Pelvis rotation	Pelvis relative to lab	<i>z</i>
Lead knee extension	Shank relative to thigh ( $180 - x^\circ$ )	<i>x</i>
Lead foot rotation	Foot relative to lab	<i>z</i>

### 3.4 Statistical Analysis

Inter rater reliability was assessed for all kinematic variables in the Pitching Mechanics Tool. For inter-rater reliability, separate Cohen's Kappa (*k*) statistics was calculated using the responses from all pitching coaches, compared to the gold standard PMT category calculated using the motion capture system. Separate Cohen's Kappa (*k*) statistics was calculated for each pitching coach, for the hardest fastball across all 11 pitchers.

For intra-rater reliability, an intra-class correlation coefficient was calculated for each kinematic variable in the PMT, by pitching coach, across three sessions. For all statistical tests, significance levels were set to  $P < 0.05$ . Landis and Koch's (1977) interpretation of results was used to express magnitude of agreement, with  $k$  values  $< 0$  indicating no agreement, 0–0.20 as slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1 as almost perfect agreement.

Inter-rater reliability was assessed by the number of answers that could be replicated amongst all 6 evaluators. A perfect parameter score was a correct answer for 6 evaluators' x 9 pitchers analyzed for 54 correct responses. Intra-rater reliability was assessed by the consistency of each pitching coach's responses, which was measured by the number of errors. Each parameter had a possible number of 3 (days) x 9 (pitchers) errors. A low number of errors was represented by a higher degree of intra-rater reliability.

A Pearson's chi-square test was used to determine significance between expected angles calculated via V3D (independent variable) and the observed values derived by the pitching coaches (dependent variable). The test for validity was run in the IBM SPSS Software platform where the chi-square test concludes whether a significance exists (McHugh, 2013). Statistical significance was set at  $< 0.05$ . Additionally, an absolute agreement test was run for all six evaluators across all 16 kinematic parameters for all three sessions to establish validity for the PMT.

### 3.5 Results

#### 3.5.1 Demographics

Eleven healthy male pitchers participated in the study (Table 9). Each pitcher was able to complete the full protocol of 30 pitches (15 fastballs and 15 curveballs).

**Table 9.** Demographic breakdown of pitchers

Pitcher	Age (years)	Height (cm)	Weight (kg)	Highest Level of Pitching	Min Fastball Velocity (mph)	Max Fastball Velocity (mph)
1	28	188.0	88.5	OUA	69	81
2	23	193.0	83.9	OCAA	74	79
3	21	172.7	70.3	Senior Ball	67	70
4	23	182.9	79.4	OUA	76	80
5	22	193.0	93.0	OUA	67	76
6	22	175.3	67.1	OUA	78	81
7	20	172.7	86.2	OUA	70	82
8	24	188.0	95.3	NJCAA	70	81
9	23	190.5	67.1	OUA	75	83
10	23	185.4	84.4	OUA	74	80
11	21	188.0	87.1	OUA	69	85
Average	22.7 ± 2.1	184.5 ± 7.3	82.0 ± 9.4	N/A	71.7 ± 3.6	79.8 ± 3.8

Note: Orange represents the maximum in each category, grey represents the minimum in each category

Six evaluators completed the Pitching Mechanics Tool, which evaluated pitching kinematics for the hardest thrown fastball for each pitcher (Table 10). The median age of the evaluators was 23.5 years and the median experience across all six evaluators was 5.5 years. Four of the six evaluators were coaches who have worked in various levels of baseball including the minor leagues, NCAA, and Collegiate Summer League. One of the evaluators was a scout who has evaluated professional baseball players for five years during the Arizona Fall League,

and one evaluator was an analyst and baseball writer who has covered the game for online baseball analysis platforms.

**Table 10.** Demographic breakdown of evaluators

Evaluators	Age (Years)	Experience (Years)	Highest Level
1	48	25	MiLB
2	24	6	Online baseball publications
3	23	5	Collegiate Summer League/NCAA Division I
4	23	5	Arizona Fall League
5	24	6	NCAA Division II
6	22	5	NCAA Division I
Median	23.5	5.5	N/A

Note: Orange represents the maximum in each category, grey represents the minimum in each category

### 3.5.2 Performance Analysis

Performance data was collected and summarized for all 11 pitchers (Table 11). Pitcher 6 had the highest average fastball velocity at  $80.1 \pm 0.9$  mph, while pitcher 3 had the lowest average fastball velocity at  $68.4 \pm 1.1$  mph. The highest fastball velocity across all pitchers was 85 mph, thrown by pitcher 11. The slowest fastball velocity across all pitchers was 67 mph, thrown by pitcher 5. Time between pitches was up to the discretion of the pitchers and was not measured for the purposes of this study.

**Table 11.** Pitch velocity for each pitch and pitcher collected. Yellow denotes the maximum fastball velocity, green denotes the minimum fastball velocity

Pitchers												
	Pitch	1	2	3	4	5	6	7	8	9	10	11
Fastball (mph)	1	69	75	67	80	67	79	70	78	76	74	69
	2	71	75	70	80	68	80	76	80	75	76	74
	3	74	76	66	78	70	80	77	81	78	78	75
	4	72	76	68	78	71	78	75	80	76	78	74
	5	74	76	68	78	72	80	82	79	76	78	78
Curveball (mph)	1	61	57	58	66	59	69	60	69	63	57	60
	2	59	58	55	67	61	67	60	68	65	57	63
	3	58	55	57	66	61	72	59	66	64	60	70
	4	60	55	58	66	61	69	60	66	66	57	67
	5	60	58	56	69	61	68	54	69	63	58	69
Fastball (mph)	6	71	75	67	78	72	79	79	78	83	77	79
	7	77	74	70	76	69	81	83	79	77	78	80
	8	78	78	69	79	71	80	79	79	81	79	85
	9	77	79	68	78	69	80	80	81	82	78	80
	10	77	79	68	78	71	81	81	77	79	79	81
Curveball (mph)	6	64	58	55	67	62	69	56	69	62	61	68
	7	63	59	57	68	62	68	58	64	62	61	69
	8	61	59	58	66	63	67	57	63	60	61	68
	9	63	59	57	67	61	69	58	61	61	61	68
	10	64	59	56	67	62	68	56	63	61	59	68
Fastball (mph)	11	78	76	69	80	70	81	80	75	83	79	79
	12	78	79	69	79	71	81	80	70	81	80	81
	13	78	77	68	78	69	81	80	73	77	80	82
	14	80	78	70	78	72	80	80	74	77	80	83
	15	81	78	69	79	76	80	82	78	80	80	83
Curveball (mph)	11	62	58	57	67	63	67	57	65	66	60	70
	12	64	59	57	65	62	69	58	64	63	62	68
	13	63	61	57	66	63	67	55	63	61	61	69
	14	60	58	60	66	61	66	58	61	63	57	68
	15	63	62	57	66	62	66	56	60	65	57	69
<b>Average Fastball Velocity per Pitcher (mph)</b>		75.7 ± 3.5	76.7 ± 1.6	68.4 ± 1.1	78.5 ± 1.0	70.5 ± 2.1	80.1 ± 0.9	78.9 ± 3.2	77.5 ± 3.1	78.7 ± 2.6	78.3 ± 1.6	78.9 ± 4.1
<b>Average Fastball Velocity (mph)</b>		76.6 ± 4.4										
<b>Average Curveball Velocity (mph)</b>		62.3 ± 4.3										



### **3.5.3 3D Kinematic Analysis and Gold Standard Bin Selection**

Table 12 summarizes the number of pitchers in each bin for all 16 parameters. For throwing arm elbow flexion, five pitchers fell into Bin 2, while six were in Bin 3. The forearm was in neutral for all 11 pitchers. Six of 11 pitchers were in Bin 2 for shoulder horizontal abduction, four were in Bin 1 and a one pitcher was in Bin 3. Shoulder abduction had seven of the 11 pitchers in Bin 2 while nine pitchers were in Bin 3 for external rotation.

Three of the 16 parameters analyzed were related to the trunk. Bin 2 was common in seven of 11 pitchers for trunk rotation, while six of 11 pitchers were in Bin 1 for lateral tilt (the other five were in Bin 2).

**Table 12.** Kinematic analysis across all 11 pitchers at lead foot strike

		Number of pitchers in each bin				
Parameters	Average	1	2	3	4	5
Elbow Flexion	79.5 ± 5.3°	0	5	6	0	0
Forearm Rotation	-10.3 ± 7.7°	0	11	0		
Horizontal Abduction	-29.3 ± 13.6°	4	6	1		
Shoulder Abduction	93.4 ± 7.0°	3	7	1		
External Rotation	139.6 ± 6.4°	0	2	9		
Trunk Rotation	73.0 ± 4.5°	1	7	3		
Trunk Lateral Tilt	-9.7 ± 3.3°	6	5	0		
Trunk Forward Flexion	1.3 ± 3.5°	5	0	6		
Pelvis Rotation	25.4 ± 15.2°	4	7	0		
Lead Knee Extension	124.7 ± 2.5°	1	6	4		
Lead Foot Rotation	175.9 ± 6.5°	1	4	1	5	
Lead Foot Strike	N/A	6	1	4		
<b>Glove Arm</b>						
Elbow Flexion	101.2 ± 6.6°	0	0	8	3	0
External Rotation	35.1 ± 6.0°	10	1	0		
Shoulder Abduction	71.6 ± 4.2°	9	2	0		
Horizontal Abduction	-51.0 ± 10.3°	11	0	0		

Six pitchers were in Bin 3 for trunk forward flexion, whereas the other five pitchers were in Bin 1. Seven of 11 pitchers were in Bin 2 for pelvis rotation while four pitchers were in Bin 1.

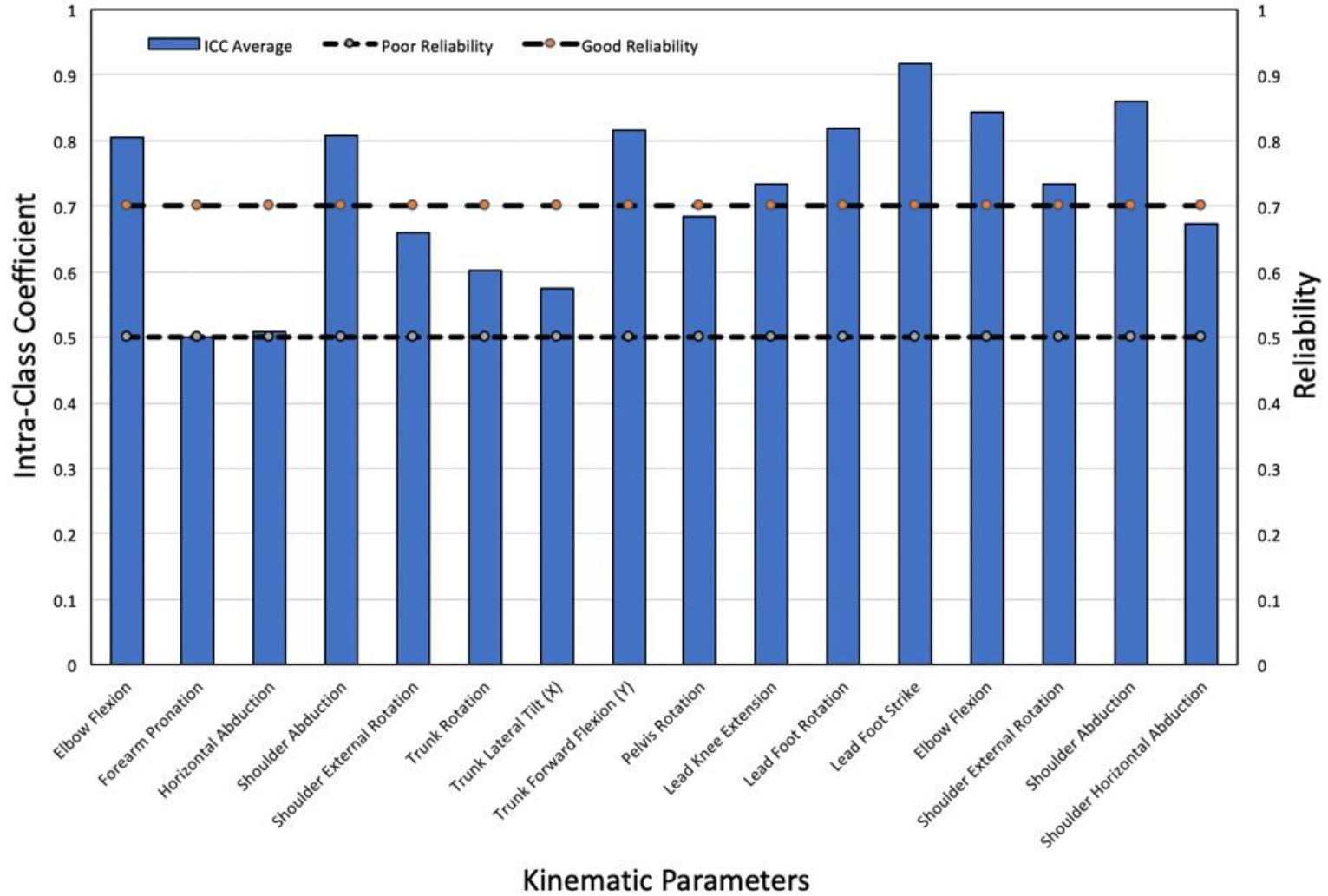
Three of the 16 parameters analyzed the front leg and lead foot at lead foot strike. Lead knee extension was in Bin 2 for six of 11 pitchers and Bin 3 for four pitchers. The lead foot was openly rotated in five pitchers and angled in four pitchers. Six pitchers landed toe first, four landed heels first, and one landed flat-footed.

Four parameters looked at the glove arm. Seven pitchers were in Bin 3 for elbow flexion, and four pitchers were in Bin 4. In terms of shoulder external rotation, 10 pitchers were in Bin 1, while nine pitchers were classified as Bin 1 for shoulder abduction. All 11 pitchers were in Bin 1 for horizontal abduction. For full results reference Appendix F.

#### **3.5.4 Intra-Rater Reliability**

*Hypothesis 1a. The PMT will demonstrate high intra-rater reliability for evaluators across multiple sessions*

For the purpose of establishing intra-rater reliability, it was necessary to investigate how well each of the six coaches scored on the Pitching Mechanics Tool across all three attempted sessions (Figure 17). ICC values ranged from 0.5 to 0.918 with the largest for parameter 12 (lead foot strike) and the smallest for parameter 2 (forearm rotation in the throwing arm). Good reliability was demonstrated in nine of 16 body segments, including shoulder abduction in the glove arm (0.859), elbow flexion in both arms (0.805 in the throwing arm; 0.843 in the glove arm), and trunk forward flexion (0.817).

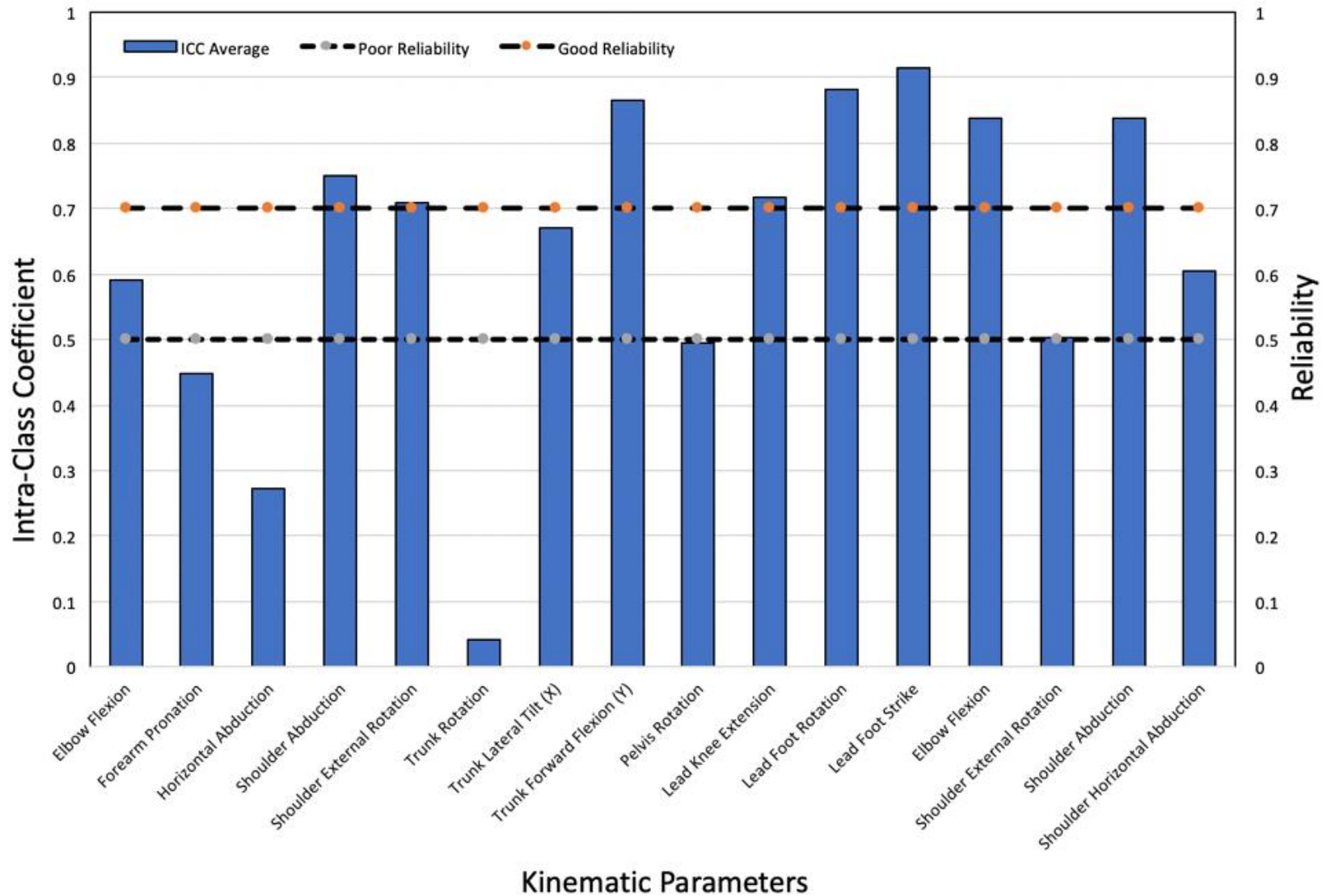


**Figure 17.** ICC values for intra-rater reliability for each evaluator across three sessions for all 16 kinematic parameters

### **3.5.5 Inter-Rater Reliability**

*Hypothesis 1b. The PTM will demonstrate high inter-rater reliability across multiple evaluators*

ICC's was used to establish inter-rater reliability (Figure 18). ICC's ranged from 0.041 in trunk rotation to 0.915 in lead foot position at lead foot strike. Good reliability was observed in eight of the 16 parameters, including trunk forward flexion (0.865), lead foot rotation (0.882), and shoulder abduction in the glove arm (0.839).

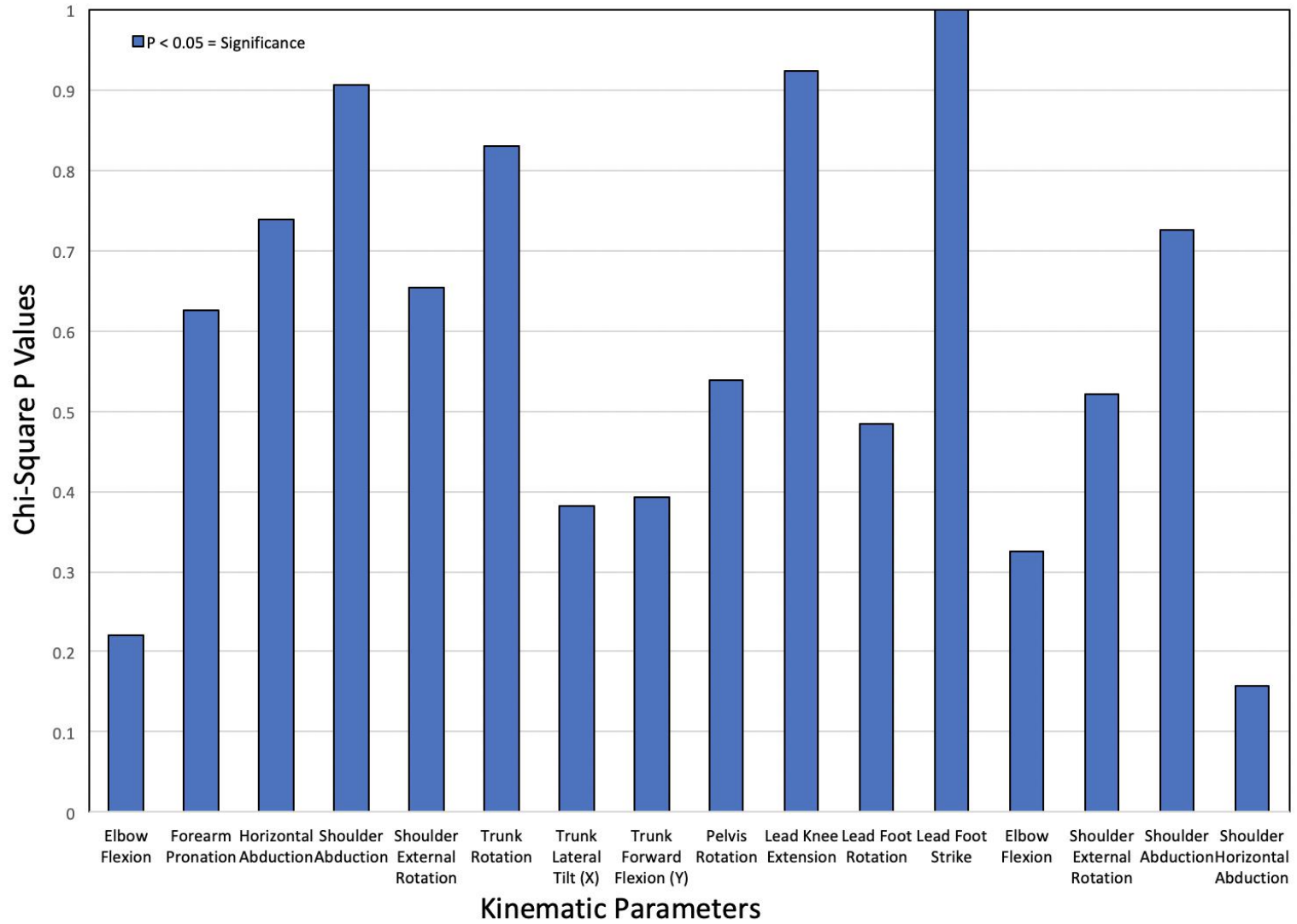


**Figure 18.** ICC's for inter-rater reliability across all six evaluators for all 16 kinematic parameters

### **3.5.6 Validity**

*Hypothesis 2a. Validity would be better for larger body parts like the trunk and less valid for smaller body parts such as the forearm or elbow*

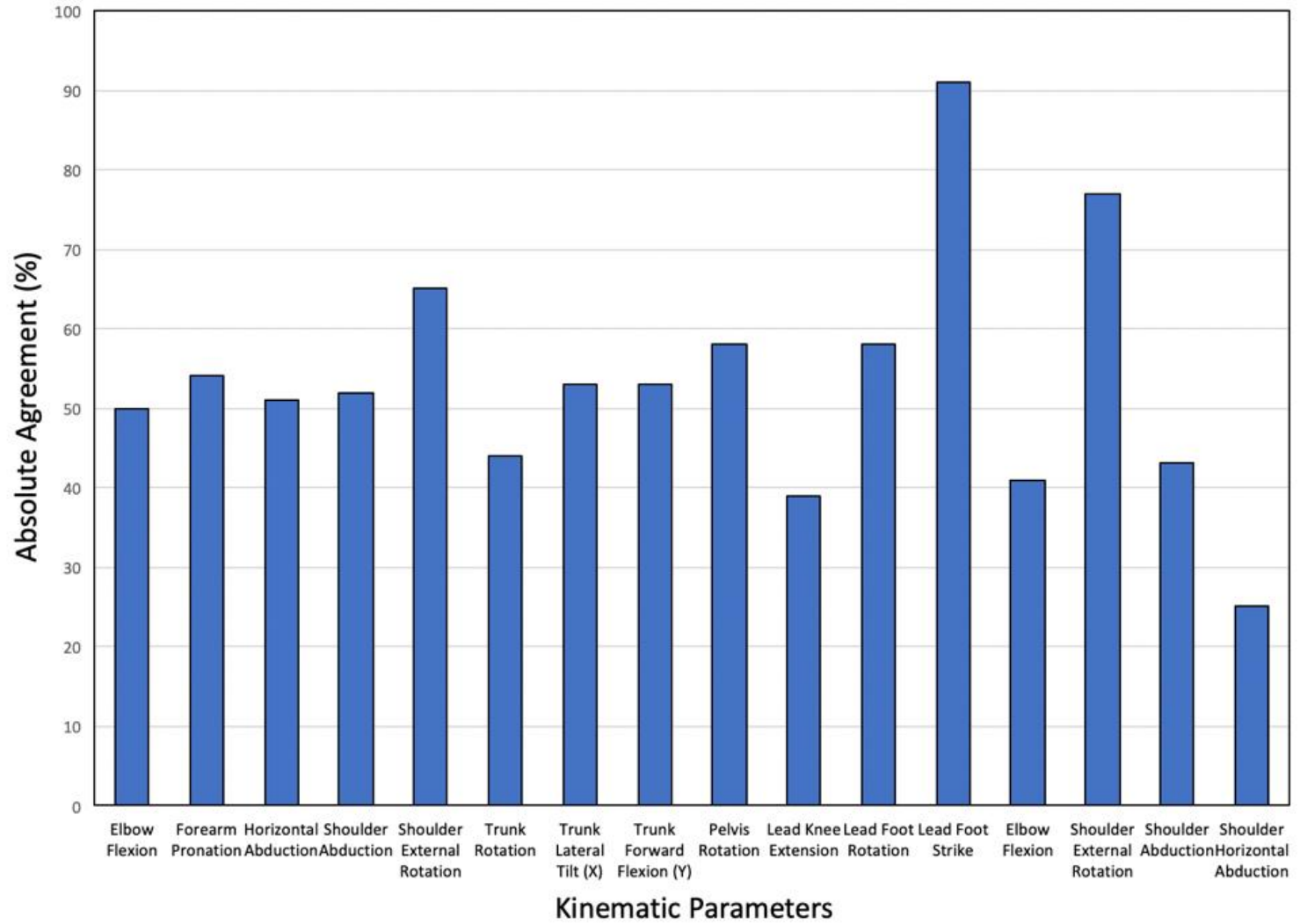
Chi Square Tests (Figure 19) for validity range from 0.157 (shoulder horizontal abduction in the glove arm) to 1.000 (foot position at foot strike). Since the values for each of the 16 parameters exceeded 0.05, it can be confirmed that no statistical significance was observed in either of the 16 kinematic parameters, meaning the evaluators were able to identify the bins correctly.



**Figure 19.** Pearson Chi-Square test for validity of all 16 kinematic parameters



Absolute agreement was deduced across all evaluators for all 16 parameters across all three sessions (Figure 20). Absolute agreements of at least 50% were observed in 11 of the 16 body segments, including in forearm pronation (54%), shoulder external rotation in the throwing arm (65%) and in the glove arm (77%). Lead foot strike showed the highest percent agreement at 91% and Bin 16 showed the lowest at 25%.



**Figure 20.** Absolute agreement across all evaluators for all 16 kinematic parameters across three sessions

## **3.6 Discussion**

### **3.6.1 Main Findings**

This thesis selected 16 body specific kinematic parameters and used a posture binning technique to provide posture-based categories for each body parameter. Termed the Pitching Mechanics Tool (PMT), the goal was to provide a tool for assessing pitching mechanics that was both valid and reliable. During the pitching delivery, it has been confirmed that the instant of lead foot strike produces the greatest stress on the throwing elbow (Fehr et al., 2016). Therefore, the PMT was developed to evaluate posture at lead foot strike. The purpose of this study was to develop an effective tool that can provide a fast, accurate, simple-to-use and low-tech option for evaluating pitching mechanics and posture at lead foot strike. It is important for such a tool to be capable of being utilized outside of the laboratory setting, on a field of play by baseball scouts and coaches. Moreover, the tool was designed as an alternative to the expensive and time-consuming 3D motion capture. It was also developed to be easy to use by those with relatively little knowledge in the field of biomechanics. Six evaluators completed the study and all were able to complete the kinematic assessments for each session in under an hour, suggesting that the PMT can very much be a quick application tool.

Intra-rater reliability was established for every individual evaluator across each of their three completed sessions, and inter-rater reliability was established between all six evaluators. Acceptable intra- and inter-class reliability was determined in nine and eight of our 16 parameters, respectively. ICC's for intra-class reliability ranged from 0.500 to 0.918, while ICC's for inter-class reliability ranged between 0.041-0.915. Validity was established across all 16 kinematic parameters. ICC's for intra-class reliability ranged from moderate to very good

(Figure 17). The results compared favourably to other ergonomic assessment tools. Similar to other tools such as RULA and REBA, the PMT takes on a similar template and much like both ergonomic assessment tools, the PMT assesses posture at a point of greatest force occurrence. Valentim et al., 2018 utilized RULA on a 156-person sample size to assess biomechanical exposure to work-place MSDs, demonstrating intra-rater reliabilities which ranged from poor to almost perfect (ICC = 0.00-0.93). A separate investigation (Dockrell et al., 2010) evaluated children computer-related posture with RULA and found a similar range to the PMT for intra-rater reliability (ICC = 0.47-0.84). Using the REBA tool, another study (Schwartz, Albin & Gerberich, 2019) evaluated custodian workers for exposure to MSD risk and showed a similar high intra-rater reliability as the PMT (ICC = 0.918).

The PMT followed a similar model as that of the RULA and REBA tools in the sense that bin-based assessments were utilized for analyzing body posture. Outside of the head and neck region, the PMT looks at the same body segments as both tools. The PMT experienced similar validation concerns as these two tools, specifically in terms of the discrepancies found between the evaluators and body segment angles located at the border of two separate bins (McAtamney & Corlett, 1993). As RULA and REBA are applied to less dynamic, work-related tasks which generate less force (Madani & Dababneh, 2016), evaluators are far more accurate in their assessments as compared to the PMT (Abdu-Rajab et al., 2010).

The Rapid Office Strain Assessment (ROSA) is a tool developed to evaluate computer work-based musculoskeletal stress. To investigate the validity and reliability of the tool, 23 office work-station were assessed through five different photos by three ergonomists (Liebregts, Sonne & Potvin, 2016). Similar to the PMT, the study determined that photo

perspective error due to the conditions of the data collection environment had an effect on the evaluators' estimation error. Moreover, a study determined that full-body images were best observed from a distance of 4.5 meters, optimal for preventing distortion of the head and feet (Paul & Douwes, 1993). In the case of the full-body images included in the PMT, the position of the cameras prevented the experimenters from receiving optimal images of the shoulder and trunk position at front foot strike. Abdu-Rajab and colleagues (2010) found that neutral joint postures are assessed far more accurately than those with greater joint deviations. Tools such as ROSA or RULA evaluate individual in work-place environments who more than likely display greater cases of neutral joint posture than the baseball pitchers evaluated by the PMT. Since pitching is a dynamic and athletic movement, the presence of extreme body posture will be elevated, leaving greater room for error. ROSA results were similar to past studies which suggested that larger joints, such as the trunk and lower body, are easier to assess compared to smaller joints, such as the arms and wrists (Baluyut et al., 1995). Mouse and keyboard-based tasks involving wrist flexion and extension or wrist deviation presented lower levels of accuracy (Liebregts, Sonne & Potvin, 2016). Similarly, in the PMT, trunk lateral tilt and forward flexion displayed superior reliability scores as compared to some parameters related to the forearm, elbow and shoulder. Lead knee extension, lead foot rotation and lead foot strike all showed good intra- and inter-rater reliability as well for the PMT. Takala and colleagues (2010) found a comparable case for the REBA tool, which displayed moderate to good inter-rater repeatability in the trunk and lower body compared to the upper limbs.

Good reliability was shown in eight of the 16 bins (Figure 18) for inter-class reliability, including lead knee extension, lead foot rotation, lead foot strike, and glove arm elbow flexion.

ICC values ranged from poor to excellent (ICC = 0.041-0.915). A limitation of the PMT was the difficulty for the evaluators to interpret certain bins, which was evident by the poor inter-rater reliability values measured in forearm pronation (0.448), horizontal abduction (0.273), trunk rotation (0.041), and pelvis rotation (0.494). The limitation comes as a result of subjective kinematic analysis being performed by human evaluators attempting to replicate objective quantitative data. Two separate studies utilized the RULA assessment tool to evaluate posture in varying age groups and determined the following inter-rater reliabilities; Valentim et al., 2018 observed ranges varying from poor to moderate (ICC = 0.00-0.53), while Dockrell et al., 2010 observed ranges varying between moderate to good (ICC = 0.50-0.77). A Schwartz, Albin & Gerberich, 2019 study utilizing the REBA tool for assessing custodian workers observed a poor intra-rater reliability (ICC = 0.41) as well.

A Pearson's chi square test established validity and determined no significant difference between the correct bin selection for each body segment using the gold standard 3D kinematics and the observed values by the evaluators. Therefore, the null hypothesis was rejected. Values ranged between 0.157 and 1.000, otherwise confirming that the PMT can provide an accurate and low technology option for binning pitching postures. Success rate appeared to be dependent on the angle ranges of the bins as evaluators displayed far better accuracy compared to the 3D motion capture alternative on parameters with large angle ranged bins. Nevertheless, results did suggest that 2D qualitative analysis is a viable option for evaluating mechanics. The results were in line with a study composed of 26 healthy adults performing a single-leg squat for the purpose of determining 2D and 3D motion capture of joint displacements at the trunk, knee, hip, and ankle in the frontal and sagittal plane. The findings

verified that 2D motion capture lacked the precision and ability to capture rotation as compared to 3D analysis (Schurr S.A., et al., 2017). Similarly, PMT findings showed reduced accuracy analyzing rotation, specifically in pelvis and lead foot rotation.

Outside of the PMT, there are other validated assessment tools that exist in the realm of baseball. Nicholls et al., 2003 developed the QAP, which consisted of 24 kinematic parameters assessed at various stages of the pitching motion. Of the 24 kinematic parameters, eight were calculated at the point of lead foot strike, including foot angle, arm abduction, external rotation and elbow flexion which are parameters in the PMT (Nicholls et al., 2003). Similar to our study, 3D-motion capture (Motion Analysis System, California) data and high-speed video of pitchers were collected. 2D Video was recorded from the open-side as well as from behind the indoor mound. Contrary to our study which only identified the highest velocity fastball of each pitcher for further analysis, the three fastest pitches thrown for strikes from each of the 20 pitching participants were taken for further analysis and two independent raters were tasked with using the collected 2D video data for kinematic analysis (Nicholls et al., 2003). For our study, six independent evaluators were recruited. Additionally, the independent reviewers attempting the QAP did not receive any form of feedback or training. Only four QAP variables proved to accomplish statistical significance in their ability to be replicated via the evaluators. Of the 24 kinematic parameters (kappa coefficients between 0.400-0.900), intra-rater reliability was significant in 22 parameters at  $P < 0.05$ . At the point of lead foot strike, strong intra-reliability was measured in abduction, external rotation, elbow flexion, and foot angle (Table 4). For the PMT, strong reliability was observed in three of the aforementioned parameters, except for elbow flexion. Inter-rater reliability was significant in only eight of the parameters at  $P < 0.05$

(Nicholls, et al., 2003). Similar to our study, significant agreement was observed at foot angle, external rotation and shoulder abduction at lead foot strike. Statistical significance was reached for use of glove arm and maximum external rotation in the arm cocking phase and for lateral trunk tilt and shoulder abduction at the instant of ball release (Table 4). The results suggested that the QAP was limited due to a subjective qualitative checklist and poor visual evaluation of the parameters compared the gold standard data (Nicholls et al., 2003).

Ultimately, the QAP and the PMT are tools that confirm that alternative methods to kinematic analysis exist and while qualitative analysis does not uphold the same accuracy as 3D motion capture, both tools are comparable in both reliability and validity to the industry gold standard. A similar study was carried out by Quatromoni, 2015 and much like the Nicholls et al., 2015 study, laid the foundation for the development of the PMT. The study looked to establish the intra- and inter-rater reliability of six biomechanical errors in youth pitchers that could contribute to the creation of an assessment tool, applicable in a clinical setting for coaches and sports medicine professionals. The study aimed to create a basis for a tool that can detect poor pitching mechanics prior to the occurrence of injury (Quatromoni, 2015). Biomechanical errors in a pitching delivery included forearm supination at full elbow extension, open/closed foot position between early and late cocking, backward lean at lead foot strike, open shoulder, decreased trunk to elbow angle at lead foot strike, and contralateral trunk lean at maximal shoulder external rotation prior to the acceleration phase (Figure 21).



Subject # \_\_\_\_\_ Video Date \_\_\_\_\_  
 Evaluator \_\_\_\_\_ Date of Evaluation \_\_\_\_\_

Pitch # \_\_\_\_\_

**Frontal Plane View**      **No Error** \_\_\_\_\_      **Error** \_\_\_\_\_

- |                                                                         |                                                                  |                                                                          |                          |
|-------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------|
| 1. Stride Foot Position @ SFC<br>Closed Stride Foot                     | <input type="checkbox"/> Stride Foot Toward Home                 | <input type="checkbox"/> Open Stride Foot                                | <input type="checkbox"/> |
| 2. Backward Lean @ SFC<br>line through                                  | <input type="checkbox"/> Head, Shoulders, Hips, Ankle<br>in Line | <input type="checkbox"/> Head is lateral to perpendicular<br>the ankle   |                          |
| 3. Upper Torso Rotation @ SFC                                           | <input type="checkbox"/> Lateral Shoulder Faces Home             | <input type="checkbox"/> Sternum is visible                              |                          |
| 4. Contralateral Trunk Lean<br>perpendicular @ Max shoulder ER<br>ankle | <input type="checkbox"/> Head, Torso, Ankle<br>in Line           | <input type="checkbox"/> Head is lateral to<br>line through the<br>ankle |                          |

**Sagittal Plane View**      **No Error** \_\_\_\_\_      **Error** \_\_\_\_\_

- |                                                 |                                                          |                                                                 |
|-------------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------|
| 5. Forearm Supination<br>@ full elbow extension | <input type="checkbox"/> Hand on top of ball (palm down) | <input type="checkbox"/> Hand on the side or below the<br>ball  |
| 6. Trunk to Elbow Angle<br>greater than 95°     | <input type="checkbox"/> SFC      90°-95° of Elevation   | <input type="checkbox"/> less than 90° <input type="checkbox"/> |

Evaluator's Notes: \_\_\_\_\_  
 \_\_\_\_\_

**Total # Errors:** \_\_\_\_\_

**Figure 21.** Pitching error scoring system to identify faulty mechanics for six biomechanical parameters at various points in the pitching delivery (Quatromoni, 2015)

The study recruited three independent raters to observe and evaluate pitching mechanics extracted from high-speed camera video. Video was not provided for our evaluators as the PMT only assessed a single phase of the pitching motion. Providing evaluators with video would create subjective definitions for the point of lead foot strike. Both studies had raters return for two additional sessions with five days in between reviews in one study (Quatromoni, 2015) and 2-5 days between the PMT study. All six errors would go onto prove to have

acceptable intra-rater reliability, whereas only three of the six errors (stride foot position at stride foot contact, backward lean at stride foot contact, and contralateral lean at maximal external rotation) had acceptable inter-rater reliability (Quatromoni, 2015). Similarly, forearm rotation at lead foot contact displayed poor agreement in the Quatromoni, 2015 study as well as in our study, but lead foot position at lead foot strike presented strong agreement in both studies (Table 7). Quatromoni, 2015 developed a framework for a tool to evaluate the pitching mechanics of youth pitchers, while the PMT developed an assessment tool to analyze the kinematics of adult pitchers.

The kinematic data calculated on the 11 collegiate level pitchers in the present study were similar to past studies related to pitching mechanics at lead foot strike (Table 13), suggesting the bin ranges utilized in the PMT were appropriate. An extensive search through scientific literature focused on collegiate and adult pitchers served as the point of reference for the development of the bins for the kinematic parameters found within the PMT. Averages and standard deviations were calculated for the purpose of creating a framework for the PMT bins. Nevertheless, there remained a certain number of kinematic parameters with bins separated by degree increments which were difficult to interpret, such as trunk lateral tilt and trunk forward flexion, which evaluators noted as being very difficult to differentiate. Of all 16 kinematic parameters, only shoulder external rotation in the throwing arm were different than the values extracted from scientific literature.

**Table 13.** Kinematic comparisons between PMT pitchers and other studies

<b>Kinematic Parameters</b>	<b>Mean ± Standard Deviation (11 Pitchers)</b>	<b>Comparable Studies (Mean ± Standard Deviation), Number of Pitchers</b>		
Elbow Flexion	79.5 ± 5.3°	Escamilla et al., 2001 (96 ± 25°), 48 adult pitchers	Escamilla et al., 1998 (84 ± 17°), 16 collegiate pitchers	Fleisig et al., 1999 (85 ± 18°), 115 collegiate pitchers
Forearm Pronation	-10.3 ± 7.7°	N/A	N/A	N/A
Horizontal Abduction	-29.3 ± 13.6°	Escamilla et al., 2001 (-26 ± 12°), 48 adult pitchers	Escamilla et al., 1998 (-20 ± 10°), 16 collegiate pitchers	Sakurai et al., 1993 (-20 ± 8°), 6 collegiate pitchers
Shoulder Abduction	93.4 ± 7.0°	Escamilla et al., 2001 (92 ± 9°), 48 adult pitchers	Escamilla et al., 1998 (98 ± 12°), 16 collegiate pitchers	Sakurai et al., 1993 (83 ± 12°), 6 collegiate pitchers
Shoulder External Rotation	139.6 ± 6.4°	Werner et al., 2001 (99 ± 17°), 40 adult pitchers	Sakurai et al, 1993 (106 ± 22°), 6 collegiate pitchers	
Trunk Rotation	73.0 ± 4.5°	Oi, 2018 (64.6 ± 12.8°), 28 collegiate pitchers	Stodden, 2001 (71 ± 15°), 19 adult pitchers	
Trunk Lateral Tilt	-9.7 ± 3.3°	Oi, 2018 (-1.0 ± 10.1°), 28 collegiate pitchers	Dowling, 2016 (-8 ± 8°), 215 adult pitchers	
Trunk Forward Flexion	1.3 ± 3.5°	Oi, 2018 (6.7 ± 8.8°), 28 collegiate pitchers	Dowling, 2016 (7 ± 11°), 215 adult pitchers	
Pelvis Rotation	25.4 ± 15.2°	Stodden, 2001 (27 ± 13°), 19 adult pitchers	Oi, 2018 (45 ± 12.6°), 28 collegiate pitchers	
Lead Knee Extension	124.7 ± 2.5°	Werner et al., 2001 (133 ± 10°) 40 adult pitchers	Fleisig et al., 1999 (132 ± 12°), 115 collegiate pitchers	
Lead Foot Rotation	175.6 ± 6.5°	N/A	N/A	N/A
Lead Foot Strike	N/A	N/A	N/A	N/A
<b>Glove Arm</b>				
Elbow Flexion	101.2 ± 6.6°	N/A	N/A	N/A
Shoulder External Rotation	35.1 ± 6.0°	N/A	N/A	N/A
Shoulder Abduction	71.6 ± 4.2°	N/A	N/A	N/A
Shoulder Horizontal Abduction	-51.0 ± 10.3°	N/A	N/A	N/A

\* N/A signifies that no past studies assessed the kinematic parameter in adult pitchers

No studies were completed on forearm pronation, lead foot rotation, and glove arm kinematics in adult pitchers at lead foot strike, therefore no subsequent comparisons could be drawn with this study. That being said, one study looked at forearm and wrist rotation at various phases of the pitching delivery, excluding the point of lead foot strike, and observed  $7 \pm 20^\circ$  of forearm pronation during the arm acceleration phase (Barrentine et al., 1998). These findings suggest that the bin ranges created for forearm pronation in the PMT were too wide, subjecting all 11 pitchers into one bin.

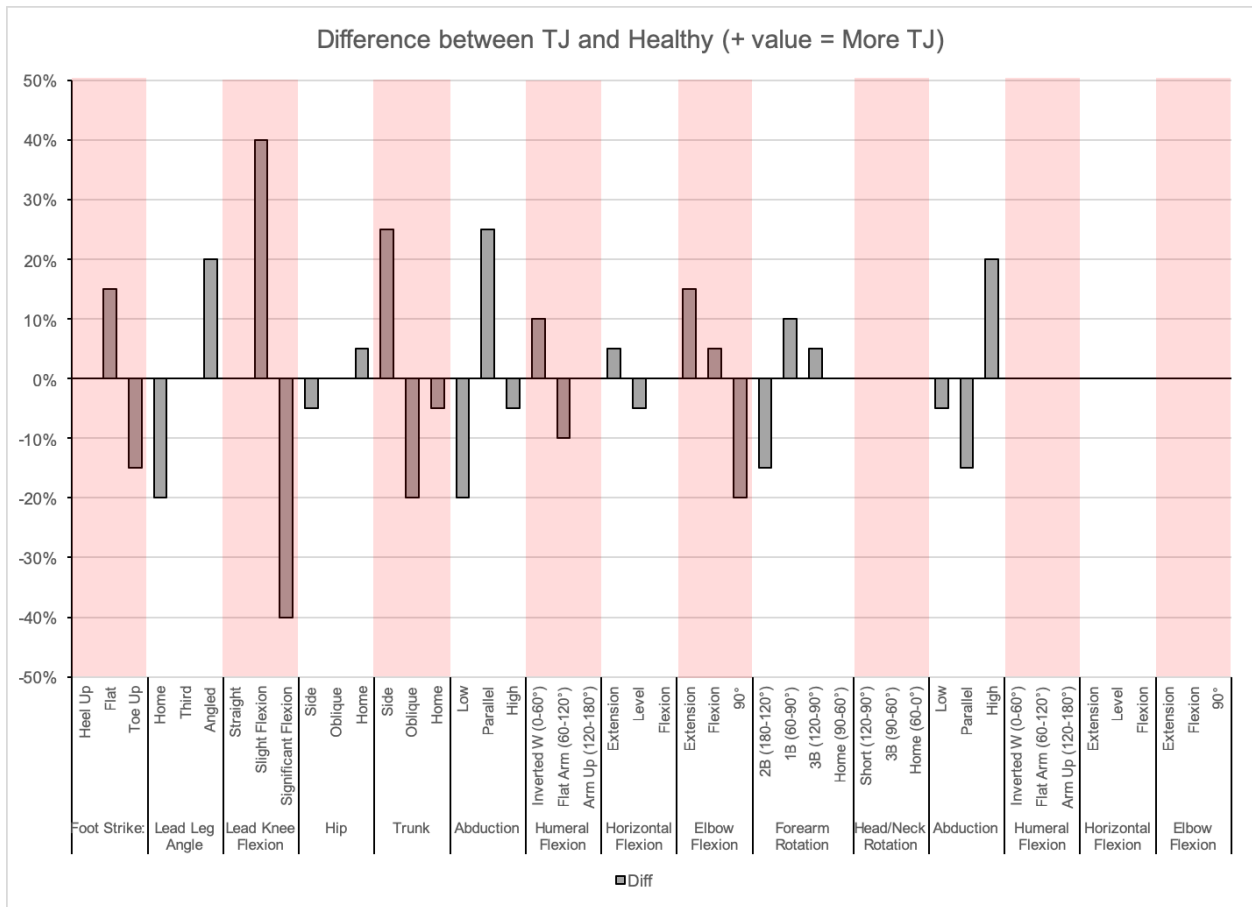
At this point, the PMT is limited as it does not output a total postural score, which is related to a certain level of associated risk much like more common ergonomic assessment tools do. Nevertheless, it does illustrate the bin ranges using clear visuals, effectively outlining each step in an organized figure, and can advise pitchers on various ways to adjust their mechanics to reduce potential risk of injury. The fabricated laboratory mound was different than a traditional pitching mound, because we needed pitchers to throw on a mound with embedded force plates. The mound utilized in this study was built for the purpose of data collection and identifying the point of lead foot strike. The distance from the mound to the net, which acted as home plate in the study, was not regulation-sized due to the size of the laboratory. To limit and prevent memorization, the order of the pitchers which the evaluators analyzed was randomized with each session and as the evaluators only received feedback on just the two trial pitchers, they were unable to verify whether they binned the following nine pitchers correctly. The study was also limited due to the use of 60 Hz video cameras which effected the quality of the images provided to the evaluators in the PMT. The angle and distance from which the videos were taken played a critical role as well. Moreover, the

subjective qualitative checklist of the PMT reduces the replicability of the data. Additionally, further analysis showed that absolute agreement increased with each session. This learning effect was not the purpose of this current work and should be further addressed in future studies.

### **3.6.2 Future Work**

The PMT tested on right-handed adult pitchers. Future work will look to test the PMT on left-handed adult pitchers and develop a version which can analyze the kinematics of pitchers on the youth and high school level. As female participation in the sport of baseball continues to grow (Osmer, 2018), it will be imperative to test the PMT on female pitchers. Past studies have shown that there are many similarities between female and male pitchers and very few significant differences in pitching kinematics (Chu et al., 2009). Furthermore, it is important to determine which of the 16 kinematic parameters in the PMT contribute most toward predicting future cases of TJS and to weigh them accordingly, therefore prioritizing the key biomechanical errors in a pitcher's mechanics. Bins can be adjusted by significance in future research based on the kinematic characteristics associated with pitchers who showed a greater risk for UCL strain. Moreover, if certain aspects are shown to be insignificant links to predicting elbow surgery, those bins should be removed from the PMT. The current version of the PMT features a number of bins with degree increments which were difficult to interpret for the evaluators. Future work will accommodate this issue and develop bins that are easier to identify subjectively.

In the initial stages of the PMT, bins for 15 kinematic parameters were created and the mechanics of 40 MLB level pitchers were evaluated. Of the 40 pitchers, 20 pitchers underwent TJS while the other 20 did not, but were comparable in velocity, role (reliever or starter), age, and handedness (Birfer, Holmes & Sonne, 2018). By determining which kinematic markers correlated more closely to TJS, a weighing system was developed in order to provide each pitcher with a biomechanical score (Figure 22). The greater the overall score, the greater the risk of future TJS. Future work will look to add a similar scoring system to the one found in the initial version of the PMT.



**Figure 22.** Difference between pre-TJS and no TJS with (+) value meaning more p-TJS (Birfer, Holmes & Sonne, 2018)

### **3.7 Conclusion**

The thesis developed a novel Pitching Mechanics Tool which provides a viable 2D qualitative alternative to 3D motion capture, but with that being said, it still fails to replicate the same level of accuracy as the industry gold standard. Nevertheless, the potential for the tool has been proven and as future works looks to improve the image capture quality and adjust the bin angle ranges for some of the kinematic parameters within the PMT, the tool can become a very usable application in the game of baseball. The PMT remains a cheaper, easier to use, and a technologically simplified method which is reliable in evaluating the kinematics of right-handed adult pitchers across multiple sessions and evaluators.

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Appendix A – Brock University REB Application

<b>Reviewer Disposition</b>			
(For REB Use Only) ▶	File #	Reviewers: _____	Due
	: _____		Date: _____
Decision:	Accepted as is <input type="checkbox"/>	Approval Pending Revision <input type="checkbox"/>	Clarification Required <input type="checkbox"/>
	Resubmission <input type="checkbox"/>	Full Review <input type="checkbox"/>	Withhold Approval <input type="checkbox"/>

**Brock University Research Ethics Board (REB)**

Application for Ethical Review of Research Involving Human Participants

If you have questions about or require assistance with the completion of this form, please contact the Research Ethics Office at (905) 688-5550 ext. 3035, or [reb@brocku.ca](mailto:reb@brocku.ca).

**Selecting a Research Ethics Board**

Files will be allocated to one of two REB panels based upon the type of research to be undertaken.

If your research involves any of the following, submit to the Bioscience Research Ethics Board (BREB):

- physiological measures such as EEGs, heart rate, GSR, temperature, blood pressure, respiration, vagal tone, x-rays, MRIs, CT or PET scans;
- ingestion or other use of food, beverages, food additives, or drugs, including alcohol and tobacco;
- medical techniques or therapies, including experimental medical devices;
- physical exertion beyond normal walking;
- physical movement in participants who have medical vulnerabilities (e.g., spinal cord injury, osteoporosis);
- human biological materials (e.g., tissues, organs, blood, plasma, skin, serum, DNA, RNA, proteins, cells, hair, nail clippings, urine, saliva, bodily fluids);
- interventions with the potential for physiological effects (e.g., diet, exercise, sleep restriction); and/or
- use of medical or official health records (e.g., hospital records).

If none of the above points are characteristic of your research, submit to the Social Science Research Ethics Board (SREB)

**Indicate which REB panel is appropriate for this application:**

Bioscience (BREB)

OR

Social Science (SREB)

Return your completed application and all accompanying material to  
[reb@brocku.ca](mailto:reb@brocku.ca)

**Researchers may submit new REB applications electronically (as PDF or Word attachments), provided that they include digital or scanned signatures. Alternatively, Principal Investigators (i.e., faculty only) may email REB applications with a note in lieu of signatures, provided that the application is sent from their Brock University email addresses. Hard copies will be accepted by the Research Ethics Office (Mackenzie Chown D250A) until January 2015.**

Handwritten Applications will **not** be accepted. Please ensure all necessary items are attached prior to submission, otherwise your application will not be processed (see checklist below).

DOCUMENT CHECKLIST	✓ if applicable
<b>2 complete sets of the following documents (one original + one copy)</b>	
Recruitment Materials <ul style="list-style-type: none"><li>• Letter of invitation</li><li>• Verbal script</li><li>• Telephone script</li><li>• Advertisements (newspapers, posters, SONA)</li><li>• Electronic correspondence guide</li></ul>	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/>
Consent Materials <ul style="list-style-type: none"><li>• Consent form</li><li>• Assent form for minors</li><li>• Parental/3<sup>rd</sup> party consent</li><li>• Transcriber confidentiality agreement</li></ul>	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Data Gathering Instruments <ul style="list-style-type: none"><li>• Questionnaires</li><li>• Interview guides</li><li>• Tests</li></ul>	<input checked="" type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>
Feedback Letter	<input checked="" type="checkbox"/>
Letter of Approval for research from cooperating organizations, school board(s), or other institutions	<input type="checkbox"/>
Any previously approved protocol to which you refer	<input type="checkbox"/>
<b>Request for use of human tissue sample in research</b> Please Note: this	

form is required for all research projects involving human tissue, bodily fluids, etc.	<input type="checkbox"/>
Signed Application Form	<input checked="" type="checkbox"/>

## SIGNATURES

**PLEASE NOTE:** The title “principal investigator” designates the person who is “in charge” of the research. In this position, the principal investigator is assumed to have the abilities to supervise other researchers, be responsible for the financial administration of the project, have the authority to ensure that appropriate guidelines and regulations are followed, and be competent to conduct the research in the absence of faculty supervision. The restriction of the term “principal investigator” to faculty or post-doctoral fellows does not have implications for ownership of intellectual property or publication authorship.

Given the above consideration, **a student cannot be identified as a “principal investigator”**. However, for the purpose of recognizing a student’s leadership role in the research, a faculty member may designate a “principal *student* investigator” below.

## INVESTIGATORS:

**Please indicate that you have read and fully understand all ethics obligations by checking the box beside each statement and signing below.**

- I have read Section III: 8 of Brock University’s Faculty Handbook pertaining to Research Ethics and agree to comply with the policies and procedures outlined therein.
- I will report any serious adverse events (SAE) to the Research Ethics Board (REB).
- Any additions/changes to research procedures after approval has been granted will be submitted to the REB.
- I agree to request a renewal of approval for any project continuing beyond the expected date of completion or for more than one year.
- I will submit a final report to the Office of Research Services once the research has been completed.
- I take full responsibility for ensuring that all other investigators involved in this research follow the protocol as outlined in this application.

### Principal Investigator

Signature \_\_\_\_\_ Date:

### Principal Student Investigator (optional)

Signature \_\_\_\_\_ Date:

### Co-Investigators:

Signature \_\_\_\_\_ Date:

\_\_\_\_\_

Signature \_\_\_\_\_ Date:

\_\_\_\_\_

#### **FACULTY SUPERVISOR:**

**Please indicate that you have read and fully understand the obligations as faculty supervisor listed below by checking the box beside each statement.**

I agree to provide the proper supervision of this study to ensure that the rights and welfare of all human participants are protected.

I will ensure a request for renewal of a proposal is submitted if the study continues beyond the expected date of completion or for more than one year.

I will ensure that a final report is submitted to the Office of Research Services.

I have read and approved this application and proposal.

Signature \_\_\_\_\_ Date:

#### **SECTION A – GENERAL INFORMATION**

1. **Title of the Research Project:** Development of a Reliable Analysis Tool for Assessing Throwing Mechanics in University-Aged Pitchers

#### **2. Investigator Information:**

	<b>Name</b>	<b>Position (e.g., faculty, student, visiting professor)</b>	<b>Dept./Address</b>	<b>Phone No.</b>	<b>E-Mail</b>
<b>Principal Investigator</b>	Michael Holmes	Assistant Professor	Applied Health Science	9056885550 x4398	michael.holmes@brocku.ca
<b>Principal Student Investigator</b>	Richard Birfer	Graduate Student	Applied Health Science	5198511433	rb17yq@brocku.ca
<b>Co-Investigator(s)</b>	Michael Sonne	Adjunct Professor	Applied Health Science	5199963746	michaelsonne@gmail.com
<b>Faculty Supervisor(s)</b>	Michael Holmes	Assistant Professor	Applied Health Science	9056885550 x4398	michael.holmes@brocku.ca

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3. **Proposed Date of commencement:**  upon approval, OR  other. Please provide date

(dd/mm/yyyy) \_\_\_\_\_

**Proposed Date of completion (dd/mm/yyyy):** June 1, 2019

4. **Indicate the location(s)** where the research will be conducted:

- Brock University   
 Community Site  Specify \_\_\_\_\_  
 School Board  Specify \_\_\_\_\_  
 Hospital  Specify \_\_\_\_\_  
 Other  Specify \_\_\_\_\_

5. **Other Ethics Clearance/Permission:**

(a) Is this a multi-centered study?  Yes  No

(b) Has any other University Research Ethics Board approved this research?  Yes  No

If **YES**, there is no need to provide further details about the protocol **at this time**, provided that **all** of the following information is provided:

- Title of the project approved elsewhere: \_\_\_\_\_  
 Name of the Other Institution: \_\_\_\_\_  
 Name of the Other Board: \_\_\_\_\_  
 Date of the Decision: \_\_\_\_\_  
 A contact name and phone number for the other Board: \_\_\_\_\_

Please provide a copy of the application to the other institution together with all accompanying materials, as well as a copy of the clearance certificate / approval.

If **NO**, will any other University Research Ethics Board be asked for approval?  Yes  No

Specify University/College \_\_\_\_\_

(c) Has any other person(s) or institutions granted permission to conduct this research?  Yes  No

If yes, specify (e.g., hospital, school board, community organization, proprietor) **provide details and attach any relevant documentation.** \_\_\_\_\_

If **NO**, will any other person(s) or institutions be asked for approval?  Yes  No

Specify (e.g., hospital, school board, community organization, proprietor) \_\_\_\_\_

6. **Level of the Research:**



- |                                                                                       |                                                                           |                                                          |
|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------|
| <input type="checkbox"/> Undergraduate Thesis                                         | <input checked="" type="checkbox"/> Masters Thesis/Project                | <input type="checkbox"/> Ph.D                            |
| <input type="checkbox"/> Post Doctorate                                               | <input checked="" type="checkbox"/> Faculty Research                      | <input type="checkbox"/> Administration                  |
| <input type="checkbox"/> Undergraduate Course<br>Assignment<br>(specify course) _____ | <input type="checkbox"/> Graduate Course<br>Assignment<br>(specify) _____ | <input type="checkbox"/> Other (specify course)<br>_____ |

**7. Funding of the Project: NSERC Discovery Grant (Holmes)**

- (a) Is this project currently being funded  **Yes**  **No**  
 (b) If **No**, is funding being sought  **Yes**  **No**

**If Applicable:**

- (c) Period of Funding (dd/mm/yyyy): From: 2015 To: 2020  
 (d) Agency or Sponsor (funded or applied for)

CIHR  NSERC  SSHRC  Other (specify): \_\_\_\_\_

- (e) Funding / Agency File # (**not** your Tri-Council PIN) RGPIN 2015-05765

**8. Conflict of Interest:**

- (a) Will the researcher(s), members of the research team, and/or their partners or immediate family members receive any personal benefits related to this study – Examples include financial remuneration, patent and ownership, employment, consultancies, board membership, share ownership, stock options. Do not include conference and travel expense coverage, possible academic promotion, or other benefits which are integral to the general conduct of research.

**Yes**  **No**

If **Yes**, please describe the benefits below.

- (b) Describe any restrictions regarding access to or disclosure of information (during or at the end of the study) that the sponsor has placed on the investigator(s).

**SECTION B – SUMMARY OF THE PROPOSED RESEARCH**

**9. Rationale:**

10. Briefly describe the purpose and background rationale for the proposed project, as well as the hypothesis(es)/research question(s) to be examined.

**Background rationale:** Numerous studies have identified overuse, high velocities, lack of rest time, and high workloads as root causes for musculoskeletal pitching injuries. It is an epidemic affecting pitchers at all age levels. Recent studies have shown that up to 58% of high school pitchers have experienced elbow pain at some point during the span of a season, while other studies have indicated that approximately 35% of boys aged 9-19 years of age have experienced shoulder pain while pitching. According to Fangraphs, there have been 341 professional baseball players in North America that have had Tommy John Elbow surgery between the years 2012 and 2016. Despite the reduction of Elbow Surgery cases over the past two seasons, the concern for a pitcher's health has continued to grow.

The biomechanical demands associated with pitching and the redundancy of the dynamic task puts an incredible amount of stress on the upper extremities. Upper extremity injuries, mainly those pertaining to the elbow and shoulder, account for 67% of all injuries to pitchers and lead to over 74 days on the disabled list in the Major Leagues. At the collegiate baseball level, 36% of complaints and days missed involve shoulder and elbow injuries.

Of all these risk factors, the most difficult to measure are the mechanics of a pitcher during a throwing motion. It has been found that muscular fatigue affects multi-joint kinematics and postural stability, which in turn can lead to poor pitch mechanics, decreases in ball velocity, and ultimately career and franchise-altering injuries. According to Mullaney et al. (2005), not all muscles fatigue at the same rate, meaning changes in muscle compensation can negatively influence pitching mechanics, leading to an increase in injury risk.

Research into pitching mechanics involves the use of expensive motion capture systems, and pitchers are not viewed in game situations, but only in laboratories. Protocols involving motion capture systems take a long time to complete, and as a result, there are typically small numbers of participants. Alternatives to motion capture are 2D video analysis, which has been shown to be inaccurate when evaluating mechanics. A study composed of 26-healthy adults performed a single-leg squat for the purpose of determining 2D and 3D motion capture of joint displacements at the trunk, knee, hip, and ankle in the frontal and sagittal plane. It was verified that 2D motion capture analysis lacks the same precision and ability to capture rotation as 3D video analysis (Schurr S.A., et al, 2017).

Various research conducted in the field of occupational biomechanics and ergonomics has long relied on the use of "posture binning techniques" to assess body mechanics in the workplace. This allows for the rapid assessment of a job and quick quantification of risk level (McAtamney & Corlett, 1993; Sonne et al., 2012). These tools have been thoroughly evaluated for inter and intra-rater reliability. No such tool exists for a similar application in the field of baseball pitching.

Pitching biomechanics are seen to change across age and skill levels as well as fatigued and non-fatigued pitchers. A quick assessment tool for evaluating pitching biomechanics would give insight into injury mechanisms.

**Purpose:** The purpose of this study is to develop an inexpensive tool which can allow for the rapid assessment of a pitcher's biomechanics, and to establish the inter and intra-rater reliability of the tool.

**Research Questions:**

1. Can 2D video analysis paired with a questionnaire on pitcher body positions be used to evaluate posture and mechanics with both high inter-rater reliability and high intra-rater reliability?

11. **Methods:**

Are any of the following procedures or methods involved in this study? Check **all** that apply.

- |                                                               |                                                                                                   |                                                                                                                                              |
|---------------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <input type="checkbox"/> Questionnaire (mail)                 | <input type="checkbox"/> Focus Groups                                                             | <input checked="" type="checkbox"/> Non-invasive physical measurement (e.g., exercise, heart rate, blood pressure)                           |
| <input checked="" type="checkbox"/> Questionnaire (email/web) | <input type="checkbox"/> Journals/Diaries/Personal Correspondence                                 | <input type="checkbox"/> Analysis of human tissue, body fluids, etc. (Request for Use of Human Tissue Sample must be completed and attached) |
| <input type="checkbox"/> Questionnaire (in person)            | <input checked="" type="checkbox"/> Audio/video taping specify)                                   | <input type="checkbox"/> Other: (specify) _____                                                                                              |
| <input type="checkbox"/> Interview(s) (telephone)             | <input type="checkbox"/> Observations                                                             |                                                                                                                                              |
| <input type="checkbox"/> Interview(s) (in person)             | <input type="checkbox"/> Invasive physiological measurements (e.g. venipuncture, muscle biopsies) |                                                                                                                                              |
| <input type="checkbox"/> Secondary Data                       |                                                                                                   |                                                                                                                                              |
| <input type="checkbox"/> Computer-administered tasks          |                                                                                                   |                                                                                                                                              |

**Describe sequentially, and in detail,** all of the methods involved in this study and all procedures in which the research participants will be involved (paper and pencil tasks, interviews, questionnaires, physical assessments, physiological tests, time requirements, etc.)

**Attach a copy of all questionnaire(s), interview guides or other test instruments. If reference is made to previous protocols, please provide copies of relevant documentation.**

**INSTRUMENTATION**

Once familiarized with all of the tasks, participants will be instrumented for our biomechanical measures.

**3D Kinematics**

Three-dimensional upper extremity kinematics will be tracked using a 10-camera Vicon System (Vicon, Oxford, UK). Individual markers will be placed over anatomical landmarks including, the suprasternal notch, xiphoid process, the hand, radial and ulnar styloids, medial and lateral epicondyles, the acromion of the dominant arm. Reflective markers will also be attached bilaterally at the lateral malleoli, lateral femoral epicondyles, greater femoral trochanters, lateral superior tip of the acromions, lateral humeral epicondyles, and the ulnar styloid process of the non-pitching wrist. Additionally, custom-molded rigid bodies consisting of light weight reflective markers will be secured to the head, sternum, and bilaterally over the

forearm, upper arm and hand (mid-segmental regions). The rigid bodies will be used to track segment movement during experimental testing. A static calibration will determine the relationship between the rigid bodies and the calibration markers over the anatomical landmarks, and subsequently joint centers and segment coordinate systems. Markers will be attached using two-sided tape and hypo-fix medical tape.

#### Pocket Radar

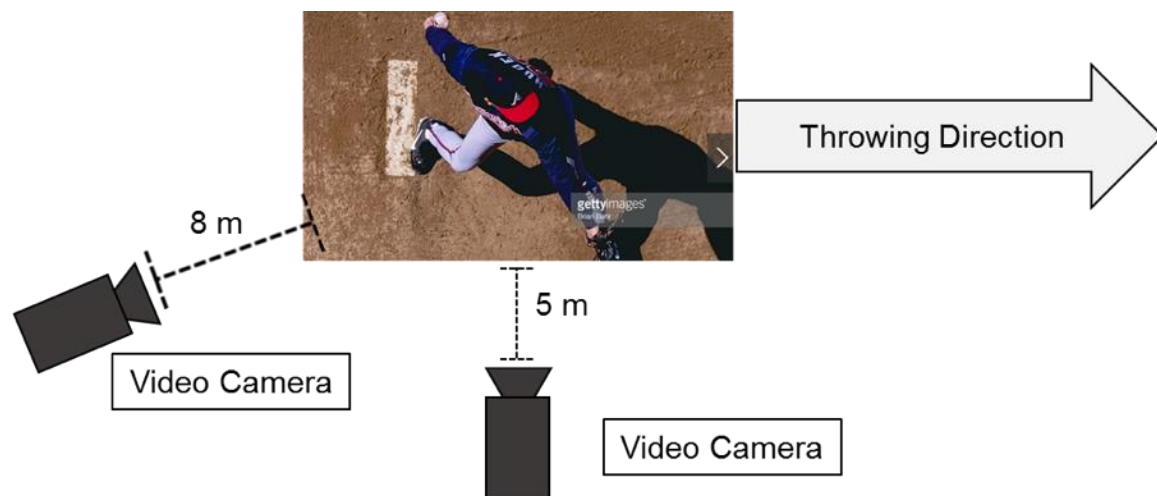
A radar gun will be used to measure ball velocity. Ball velocity will be recorded as the ball leaves the pitcher's hand. The radar gun will be calibrated before each testing session.

#### Force Plates

Ground reaction forces (GRF) are important in pitching given that the only external contact a pitcher has is between the foot and the ground. Having the ability to use force plates allows the investigator to investigate the relationship between ground reaction force and throwing mechanics in OUA overhead baseball pitchers. Two force plates (BTS P6000) will be embedded into the pitching mound.

#### Video Cameras

High speed video cameras (2) will capture the pitching motion. The first camera will be positioned orthogonally to the pitcher, to capture the front side of the body (on the right of the pitching rubber for right-handed pitchers, on the left for the left-handed pitchers). The second camera will be positioned at a 20-degree angle with respect to the pitching rubber, behind the pitcher (Figure 1). This will simulate the camera angle often used during major league baseball broadcasts.



**Figure 1:** Position of high speed video cameras with respect to the pitcher during data collection.

#### Experiment Protocol

We will recruit 11 OUA right-handed baseball pitchers for this study (age over 18) with no baseball-related injuries in the past year. They will be undergraduate/graduate students recruited from various universities. Participants will come to the neuromechanics and ergonomics laboratory to complete the experiment.

### Day 1:

Testing procedures are in accordance with previous work. Reflective markers and electromyography will be attached to the participant as described above. Each participant will be given an unlimited amount of time for stretching, warm-up throwing, pitching off an indoor pitching mound and any other type of preparation desired. Participants will be instructed to prepare just as if they were going to pitch in a game.

The data collection protocol will consist of a 30-pitch throwing session. Pitchers will throw both fastballs and curveballs, in blocks of 5 pitches (5 fastballs, followed by 5 curveballs). Each pitch will be thrown off a mound and into a net, approximately 15 meters away from the pitching rubber. Participants can take as much time between pitches as they require to prevent any fatigue from accumulating.

The pitching session will end when a pitcher reaches 30 pitches, or if they feel they could not continue because of fatigue or discomfort. Kinematics data will be collected during every pitch.

### Day 2:

The kinematic data from each pitcher will be analyzed, and the highest velocity fastball throws for each pitcher will be selected for further analysis. Image at lead foot strike will be taken from the rear side high-speed video cameras and will be displayed side by side.

We will recruit six pitching coaches, scouts, and/or baseball analysts with at least 5 years of experience working with adult baseball pitchers. The evaluators will view the images of each of the 11 pitchers we have recruited for the study. The evaluators will have the ability to view each pitch the pitcher throws, synced with two camera angles. While there will be 11 pitchers evaluated, the first two pitchers each evaluator assesses will be compared against the data from the kinematic analyses from the 3D motion capture system. The coaches will be given feedback on how they evaluated these three pitchers – errors will be noted and feedback provided.

Once evaluators feel comfortable with the questionnaire and the video system, they will evaluate the remaining 9 pitchers.

The instructions given to the pitching coaches are as follows:

1. The Pitching Mechanics Tool will evaluate a pitcher's posture at the instance of lead foot strike.
2. Each evaluator will receive a participant ID.
3. At this point, check off the postures, which are appropriate in the questionnaire. The experimenter cannot give you any feedback on your answers after the first two pitchers have been evaluated.
4. Take as much time as you want. When you are finished, let the experimenter know.

### Day 3 and 4:

The procedure from day 2 will be repeated two more times. This includes the evaluation of two practice pitchers, and providing feedback on the performance. The time between day 2, 3, and 4 will be a minimum of 2 days between each day, and a maximum of 5 days.

### Data Analysis:

### *Kinematic calculations and Pitching Mechanics Tool*

At the instant of lead foot strike, the following kinematic parameters will be measured: elbow flexion, shoulder external rotation, forearm pronation, shoulder abduction, shoulder horizontal abduction, trunk rotation (with respect to pelvis), trunk forward flexion, trunk lateral tilt, pelvis rotation lead knee extension angle, lead foot rotation, and lead foot strike. This will be calculated for the highest velocity fastball for each pitcher.

### *Inter-rater Reliability:*

The number of errors for each pitching mechanics tool parameter will be calculated between all 6 pitching coaches, and the gold standard for each pitcher. A perfect parameter score would be a correct answer for 6 coaches' x 9 pitchers analyzed for 54 correct responses.

### *Intra-rater Reliability:*

The consistency of each pitching coach's responses will be measured by number of errors. Each parameter will be a possible number of 3 (days) x 9 (pitchers) errors. A low number of errors will represent a higher degree of intra-rater reliability.

### **Development of a Pitching Mechanics Tool**

The exact tool is still under development. The Pitching Mechanics Tool will consist of static images of the forearm, upper arm, trunk, pelvis, knee, and foot position during the lead foot strike of the baseball pitching motion. Posture ranges will be binned into appropriate degree increments. The initial bin for each body segment will be established using scientific literature, after which two standard deviations from the mean will be used to create the remaining bins for each parameter. The user will check off a box if the posture of the pitcher in the video is represented by the appropriate posture bins. An example of the Rapid Upper Limb Assessment (RULA) is included below (Figure 2). This is a very popular workplace assessment tool that is postural based. The Pitching Mechanics Tool will take a similar form.

**RULA Employee Assessment Worksheet** Based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

### A. Arm and Wrist Analysis

**Step 1: Locate Upper Arm Position:**

Step 1a: Adjust...  
If shoulder is raised: +1  
If upper arm is abducted: +1  
If arm is supported or person is leaning: -1

**Step 2: Locate Lower Arm Position:**

Step 2a: Adjust...  
If either arm is working across midline or out to side of body: Add +1

**Step 3: Locate Wrist Position:**

Step 3a: Adjust...  
If wrist is bent from midline: Add +1

**Step 4: Wrist Twist:**

Step 4a: Adjust...  
If wrist is twisted in mid-range: +1  
If wrist is at or near end of range: +2

**Step 5: Look-up Posture Score in Table A:**  
Using values from steps 1-4 above, locate score in Table A

**Step 6: Add Muscle Use Score**  
If posture mainly static (i.e. held >10 minutes), Or if action repeated occurs >5% per minute: +1

**Step 7: Add Force/Load Score**  
If load = 4-8 lbs (intermittent): +0  
If load 4-4 to 22 lbs (intermittent): +1  
If load 4-4 to 22 lbs (static or repeated): +2  
If more than 22 lbs or repeated or shocks: +3

**Step 8: Find Row in Table C**  
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in Table C.

### B. Neck, Trunk and Leg Analysis

**Step 9: Locate Neck Position:**

Step 9a: Adjust...  
If neck is twisted: +1  
If neck is side bending: +1

**Step 10: Locate Trunk Position:**

Step 10a: Adjust...  
If trunk is twisted: +1  
If trunk is side bending: +1

**Step 11: Legs:**  
If legs and feet are supported: +1  
If not: +2

**Step 12: Look-up Posture Score in Table B:**  
Using values from steps 9-11 above, locate score in Table B

**Step 13: Add Muscle Use Score**  
If posture mainly static (i.e. held >10 minutes), Or if action repeated occurs >5% per minute: +1

**Step 14: Add Force/Load Score**  
If load = 4-4 lbs (intermittent): +0  
If load 4-4 to 22 lbs (intermittent): +1  
If load 4-4 to 22 lbs (static or repeated): +2  
If more than 22 lbs or repeated or shocks: +3

**Step 15: Find Column in Table C**  
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in Table C.

**SCORES**

**Table A: Wrist Posture Score**

Upper Arm	Lower Arm	Wrist Twist				
		1	2	3	4	
1	1	1	2	2	3	3
1	2	2	2	2	3	3
1	3	2	3	3	3	4
1	4	2	3	3	3	4
2	1	2	3	3	3	4
2	2	3	3	3	3	4
2	3	3	4	4	4	5
2	4	3	4	4	4	5
3	1	3	4	4	4	5
3	2	3	4	4	4	5
3	3	4	4	4	4	5
3	4	4	4	4	4	5
4	1	4	4	4	4	5
4	2	4	4	4	4	5
4	3	4	4	4	4	5
4	4	4	4	4	4	5
5	1	5	5	5	5	6
5	2	5	5	5	5	6
5	3	5	5	5	5	6
5	4	5	5	5	5	6
6	1	6	6	6	6	7
6	2	6	6	6	6	7
6	3	6	6	6	6	7
6	4	6	6	6	6	7

**Table B: Neck, Trunk and Leg Score**

Posture	Legs					
	1	2	3	4	5	6
1	1	1	1	1	1	1
2	2	2	2	2	2	2
3	3	3	3	3	3	3
4	4	4	4	4	4	4
5	5	5	5	5	5	5
6	6	6	6	6	6	6

**Table C: Neck, trunk and leg score**

Wrist and Arm Score	Neck, Trunk and Leg Score						
	1	2	3	4	5	6	7
1	1	2	3	3	4	5	6
2	2	2	3	4	4	5	6
3	3	3	3	4	4	5	6
4	3	3	3	4	4	5	6
5	4	4	4	4	5	6	7
6	4	4	4	4	5	6	7
7	5	5	5	5	6	7	7
8	5	5	5	5	6	7	7

Scoring: (final score from Table C)  
1 or 2 = acceptable posture  
3 or 4 = further investigation, change may be needed  
5 or 6 = further investigation, change soon  
7 = investigate and implement change

Task name: \_\_\_\_\_ Reviewer: \_\_\_\_\_ Date: \_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_  
This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in RULA. © 2004 Rose Consulting, Inc. rbarber@ergosmart.com (816) 444-1667

**Figure 2:** The Rapid Upper Limb Assessment (McAtamney & Corlett, 1993). The Pitching Mechanics Tool will feature a similar system, where users will check off which posture is applicable to the video of the pitcher they are watching. Risk levels will be assigned at a later date.

## 12. Professional Expertise/Qualifications:

Does this procedure require professional expertise/recognized qualifications (e.g., registration as a clinical psychologist, first aid certification)?

Yes specify: \_\_\_\_\_  No

If **YES**, indicate whether you, your supervisor, or any members of your research team have the professional expertise/recognized qualifications required?  Yes  No

## 13. Participants:

Describe the number of participants and any required demographic characteristics (e.g., age, gender).

For the study, 11 OUA right-handed baseball pitchers will be recruited for this study (age over 18) with no major injuries in the past year. They will be undergraduate/graduate students recruited from various universities.

Six pitching coaches, baseball scouts, or baseball analysts who have at least five years' experience working with or studying pitchers at a university-aged (or above) level will be recruited (18 and over).

**14. Recruitment:**

Describe how and from what sources the participants will be recruited, including any relationship between the investigator(s), sponsor(s) and participant(s) (e.g., family member, instructor-student; manager-employee).

**Attach a copy of any poster(s), advertisement(s) and/or letter(s) to be used for recruitment.**

Baseball coaches, scouts, and analysts will be contacted for permission to recruit their pitchers for the purpose of the study. We will provide them with the recruitment poster for both players and coaches. When a potential participant contacts the research team, the study will be fully explained and potential participants will be repeatedly reminded that they are free to choose whether they wish to participate in the study. If the student-athlete happens to be a Brock University student, they will be reminded that not participating in the study will in no way, now or ever, negatively impact either their grade in a course, performance in a lab, reference letter recommendations and/or thesis evaluation. The written consent form clearly states that the participant may withdraw from the study at any point without prejudice. In the event that a participant withdraws from the study, the data collected on them will be deleted. Participants are free to withdraw from the study at any time without question or prejudice. If they are taking a course with Dr. Holmes, their grade will not be affected should they withdraw from the study. However, since this may be an intimidating decision for students to make, all efforts will be made to recruit participants who are not students of the investigators, or participation will be handled by the student researcher. In the event of a student volunteer, all correspondence and data collection will be done in the presence of the research assistant only.

**15. Compensation:**

a) Will participants receive compensation for participation?

Yes  No

b) If yes, please provide details.

Participants will be reimbursed for participation with a \$5 Tim Hortons gift card. If a participant withdraws halfway through the study and can no longer complete the session, they will still be reimbursed.

**SECTION C – DESCRIPTION OF THE RISKS AND BENEFITS OF THE PROPOSED RESEARCH**

**16. Possible Risks:**



1) Indicate if the participants might experience any of the following risks:

a) Physical risks (including any bodily contact, physical stress, or administration of any substance)?

Yes  No

b) Psychological risks (including feeling demeaned, embarrassed worried or upset, emotional stress)?

Yes  No

c) Social risks (including possible loss of status, privacy, and / or reputation)?  Yes  No

d) Are any possible risks to participants greater than those that the participants might encounter in their everyday life?

Yes  No

e) Is there any deception involved?

Yes  No

f) Is there potential for participants to feel obligated to participate or coerced into contributing to this research (because of regular contact between participants and the researcher, relationships that involve power-dynamics, etc.)?

Yes  No

2) If you answered **Yes** to any of 1a – 1f above, please explain the risk.

**A. Physical risks:**

1. It is possible that redness or irritation on the skin in the area where electrodes are attached can occur. Participants will be made aware that this is a very normal reaction to the electrode procedures. It does not leave a permanent mark, with redness disappearing in 1-2 days (most people experience no redness at all).
2. Post experiment muscle soreness, similar to any low – moderate intense exercise is possible. The pitching motion is a very dynamic and full body exercise, thus when done at high effort, subjects may feel soreness. Additionally, they may experience delayed onset muscle soreness (DOMS) 24-48 hours' post experimentation.

**F. Feeling Coerced:**

If participants are taking a course with the aforementioned professor their grade will not be affected should they withdraw from the study. However, since this may be an intimidating decision for students to make, all efforts will be made to recruit participants who are not students of the investigators. In the event of a student volunteer, all correspondence and data collection will be done in the presence of the research assistant only. Participation, non-participation or withdrawal from the study will not affect one's standing at Brock University.

3) Describe how the risks will be managed and include the availability of appropriate medical or clinical expertise or qualified persons. Explain why less risky alternative approaches could not be used.

SOPs are in place for electromyography measures. All risks are on site only and all participants will be closely watched by the investigators to ensure safety. Participants will be consistently reminded throughout the duration of the protocol that, should they become too uncomfortable, they are free to withdraw from the study at any point.

For post-session skin irritation or muscle soreness we will advise participants to call the researcher, and/or their health care provider. We require to shave the forearm locations prior to electrode placement to improve the quality of our recording sites. A single-use, disposable razor will be used and if bleeding or razor burn occurs, this will become the priority, rather than continuing the protocol. The pitching motion is a very dynamic and full body exercise, thus when done at high effort, subject may feel soreness as a result. Additionally, participants may experience delayed onset muscle soreness (DOMS) 24-48 hours' post experimentation. However, we are recruiting highly competitive OUA baseball pitchers, thus pitching 30 times in one session is a low-level task for these individuals as they regularly pitch more than this in a single session.

If participants are taking a course with the aforementioned professor their grade will not be affected should they withdraw from the study. However, since this may be an intimidating decision for students to make, all efforts will be made to recruit participants who are not students of the investigators. In the event of a student volunteer, all correspondence and data collection will be done in the presence of the research assistant only.

#### **17. Possible Benefits:**

Discuss any potential direct benefits to the participants from their involvement in the project. Comment on the (potential) benefits to the scientific community/society that would justify involvement of participants in this study.

The primary benefit to participants in this study will be that it will expose them to the research environment and also to a number of different research technologies. This is of importance given that some of the participants will likely be kinesiology students who will be learning about the techniques in the classroom, thus gaining practical experience. At the end of the testing session, all participants will be given an opportunity for 'debriefing' where one of the researchers will answer any questions they may have about the protocol or results obtained in their data collection session. Participants will learn a little about baseball, specifically pitching, biomechanics and ergonomics.

### **SECTION D – THE INFORMED CONSENT PROCESS**

#### **18. The Consent Process:**

**Describe the process** that the investigator(s) will be using to obtain informed consent. Include a description of who will be obtaining the informed consent. If there will be no written consent form, explain why not.

For information about the required elements in the letter of invitation and the consent form, as well as samples, please refer to: <http://www.brocku.ca/researchservices/forms/index.php>

**If applicable, attach a copy of the Letter of Invitation, the Consent Form, the content of any telephone script, and any other material that will be utilized in the informed consent process.**

Once participants express an interest in participating in the study they will be contacted and the study will be briefly explained to them again. If they still have an interest in participating, then a time will be set-up for them to come to the lab. During this lab session, the study will be explained in more detail and participants will be given the opportunity to ask any questions they may have about the study. Once all questions are answered, participants will then be given the informed consent form to read. We will also give them the screening questionnaire to confirm that they have no history of chronic pain or neurological impairments to the upper extremity. They will also be reminded that if they have any questions while reading the form to feel free to ask them. After reading the consent form and having any additional questions answered, if participants are willing to take part in the study they will be asked to sign the informed consent form. Their witnessed signature on this form will provide evidence of their informed consent to participate in the study.

We will e-mail heads of organizations as well as athletic departments of universities and ask them to share our recruitment poster with their groups. Once interested parties contact us and we confirm eligibility, then we will send them the consent form to review via email. We will set up a time to go over the consent form with interested parties in further detail over the phone. If they have no further questions, we will invite them to participate in the study. During their first session, we will once again go over the consent form in detail with the participant. At the beginning of the first session, we will ask participants for a mailing address that we can use to mail them a gift card. Each coach will also be emailed a feedback letter that outlines the work, provides suggested reading material and gives permission for us to update them with the study findings at a later time.

**19. Consent by an authorized party:**

If the participants are minors or for other reasons are not competent to consent, describe the proposed alternative source of consent, including any permission form to be provided to the person(s) providing the alternative consent.

N/A

**20. Alternatives to prior individual consent:**

If obtaining individual participant consent prior to commencement of the research project is not appropriate for this research, please explain and provide details for a proposed alternative consent process.

N/A

## 21. Feedback to Participants:

Explain what feedback/ information will be provided to the participants after participation in the project. This should include a more complete description of the purpose of the research, and access to the results of the research. Also, describe the method and timing for delivering the feedback.

Due to the fact that data will potentially be published/disseminated, all participants will be entitled to feedback on the future publication of the data. More specifically, they will be provided with the contact information (email address) of Dr. Holmes and will be told that if they are interested in receiving future information regarding the study, they may contact the researchers directly. This contact information (email address) will be provided to the participants within the consent form. It will be explained to participants that published work can take a long time (6+ months) to become available. If they wish to see individual data along the way, they are also encouraged to contact the investigators.

## 22. Participant withdrawal:

a) Describe how the participants will be informed of their right to withdraw from the project. Outline the procedures that will be followed to allow the participants to exercise this right.

The investigators will verbally explain the study, procedures and risks to each participant. The investigators will be available to answer any questions the participants may have prior to signing the informed consent. At this time, the investigators will reiterate to participants that their participation is voluntary. They are free to withdraw or discontinue the study at any time, without consequence. If the participant is a Brock University student, their withdrawal from the study will not affect their standing at the University. We will also remind participants that they will be reimbursed for their time (even if they do not complete the study – assuming they complete 50% of it).

b) Indicate what will be done with the participant's data should the participant choose to withdraw. Describe what, if any, consequences withdrawal might have on the participant, including any effect that withdrawal may have on participant compensation.

Any participant that withdraws from this study will have their data permanently discarded and all paper copies (consent form, etc.) will be destroyed. There will be no consequences for

a participant if they choose to withdraw, even once the study is over their data can still be destroyed.

## SECTION E – CONFIDENTIALITY & ANONYMITY

**Confidentiality:** information revealed by participants that holds the expectation of privacy. This means that all data collected will not be shared with anyone except the researchers listed on this application.

**Anonymity of data:** information revealed by participants will not have any distinctive character or recognition factor, such that information can be matched (**even by the researcher**) to individual participants. Any information collected using audio-taping, video recording, or interview cannot be considered anonymous. **Please note that this refers to the anonymity of the data itself and not the reporting of results.**

23. Given the definitions above:

- a) Will the data be treated as confidential?  Yes  No  
b) Are the data anonymous?  Yes  No

c) Describe any **personal identifiers** that will be collected during the course of the research (e.g., participant names, initials, addresses, birth dates, student numbers, organizational names and titles etc.). Indicate how personal identifiers will be secured and if they will be **retained** once data collection is complete.

Participants will be identified only with subject codes. No participant names, initials or identifying markers will be used. Participants will be referred to as “subject 01”, “02”, etc. on all data collection computers. Once the study is completed, all data will be retained, but moved from the data collection computer to a secured hard drive in the PI’s office. All signed consent forms (personal identifiers) will be secured in a locked filing cabinet in a locked room, inside the locked Neuromechanics and Ergonomics Lab (TH144).

d) If any personal identifiers will be **retained** once data collection is complete, provide a comprehensive rationale explaining why it is necessary to retain this information, **including the retention of master lists that link participant identifiers with unique study codes and de-identified data.**

All signed consent forms (personal identifiers) and the master list of participant identifier codes will be secured in a locked filing cabinet in a locked room, inside the locked Neuromechanics and Ergonomics Lab (TH144).

e) State who will have access to the data.

Only the principal investigator and the principal student investigator will have access to the data.

f) Describe the procedures to be used to ensure anonymity of participants and/or confidentiality of data **both during the conduct of the research and in the release of its findings.**

The identity of each participant will be kept confidential, only available to the researchers. All data, including written records and electronic data, will be placed in a locked cabinet or stored on a secured computer in the locked office of the principal investigator. Data will be originally recorded on a computer that is password protected and only available to the researchers in a locked and secure room. The data will remain at this institution. The data will not be linked with any other data set and the data will not be sent outside of the institution where it is collected. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces.

g) If participant anonymity and/or confidentiality is not appropriate to this research project, explain, in detail, how all participants will be advised that data will not be anonymous or confidential.

N/A

h) Explain how written records, video/audio tapes, and questionnaires will be secured, and provide details of their final disposal or storage, including how long they will be secured and the disposal method to be used.

All data will be in digital form. Our data collection software allows for written notes during data collection if particular trials or conditions should not be included in the final analysis.

## SECTION F -- SECONDARY USE OF DATA

23.

a) Is it your intention to reanalyze the data **for purposes other than described in this application?**

Yes  No

b) Is it your intention to allow the study and data to be reanalyzed by colleagues, students, or other researchers outside of the original research purposes? If this is the case, explain how you will allow your participants the opportunity to choose to participate in a study where their data would be distributed to others (state how you will contact participants to obtain their re-consent)

N/A

c) If there are no plans to reanalyze the data for secondary purposes and, yet, you wish to keep the data indefinitely, please explain why.

We have no immediate plans to reanalyze the data at this time. However, analysis techniques and ideas change over time and we would prefer to have access to the data should a new analysis be performed. In addition, sometimes publication of results can take years to complete and we prefer to hold on to data in case there are ever questions about the quality or integrity of our data.

## SECTION G -- MONITORING ONGOING RESEARCH

**It is the investigator's responsibility to notify the REB using the "Renewal/Project Completed" form, when the project is completed or if it is cancelled.**

<http://www.brocku.ca/researchservices/forms/index.php>

### 24. Annual Review and Serious Adverse Events (SAE):

**a) MINIMUM REVIEW REQUIRES THE RESEARCHER COMPLETE A "RENEWAL/PROJECT COMPLETED" FORM AT LEAST ANNUALLY.**

Indicate whether any additional monitoring or review would be appropriate for this project.

--

**\*Serious adverse events** (negative consequences or results affecting participants) **must be reported** to the Research Ethics Officer and the REB Chair, **as soon as possible** and, in any event, no more than 3 days subsequent to their occurrence.

### 25. COMMENTS

If you experience any problems or have any questions about the Ethics Review Process at Brock University, please feel free to contact the Research Ethics Office at (905) 688-5550 ext 3035, or [reb@brocku.ca](mailto:reb@brocku.ca).

## Informed Consent

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Date: February 22, 2018  
Project Title: Development of a Novel Pitching Mechanics Tool

Principal Investigator (PI): Michael Holmes, Assistant Professor  
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### INVITATION

You are invited to participate in a research study. Numerous studies have identified overuse, high velocities, lack of rest time, and high workloads as root causes for musculoskeletal pitching injuries. It is an epidemic affecting pitchers at all age levels. Despite the reduction of elbow surgery cases over the past two seasons, the concern for a pitcher's health still exists. Of all these risk factors, the most difficult to measure are the mechanics of a pitcher during a throwing motion. While improper pitching mechanics may lead to injuries, correcting them would not only improve health and decrease injury risk, but it would make you as the pitcher more effective on the mound. The purpose of this study is to develop an inexpensive tool which can allow for the rapid assessment of a pitcher's biomechanics, and to establish the inter and intra-rater reliability of the tool.

### WHAT'S INVITATION

As a participant, you will be asked to throw 30 pitches (15 fastballs, 15 curve balls) off an indoor mound into a net, approximately 15 meters away from the pitching rubber. You can take as much time between pitches as you require to prevent any fatigue from accumulating. You will throw in blocks of five (5 fastballs, followed by 5 curveballs).

### EXPERIMENT PROTOCOL



You will be among 11 OUA right-handed baseball pitchers recruited for this study (age over 18) with no baseball-related injuries in the past year. You will come to neuromechanics and ergonomics laboratory to complete the experiment.

Reflective markers will be attached to various locations on your body to track your mechanics using infrared cameras positioned around the room.

The data collection protocol will consist of a 30-pitch throwing session. You will throw both fastballs and curveballs, in blocks of 5 pitches (5 fastballs, followed by 5 curveballs). Each pitch will be thrown off a mound and into a net, approximately 15 meters away from the pitching rubber. You can take as much time between pitches as you require to prevent any fatigue from accumulating.

The pitching session will end when you reach the 30-pitch limit, or when you feel you cannot continue because of fatigue or discomfort. Kinematic data will be collected during every pitch.

#### Motion Capture (3D Kinematics)

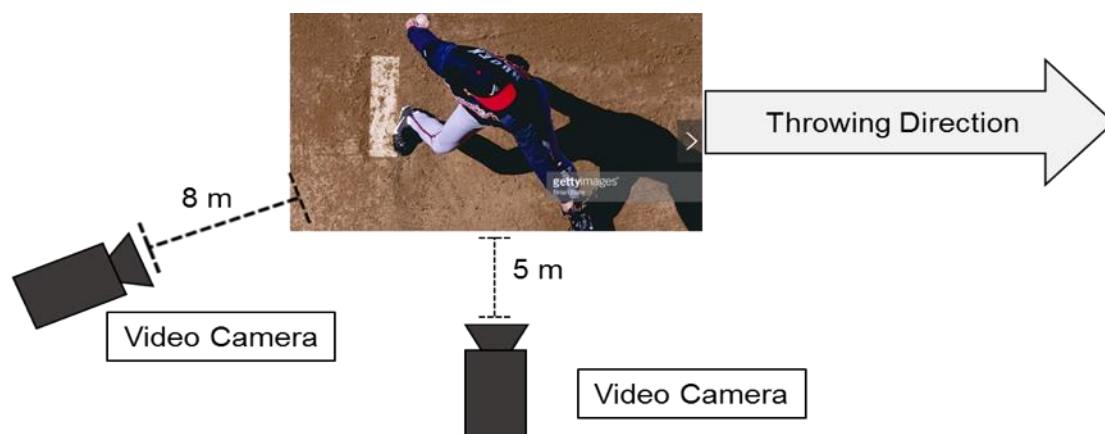
Three-dimensional motion will be tracked using a 10-camera Vicon System. Custom-molded rigid bodies consisting of light weight reflective markers will be secured to your body using double sided tape over the sternum, head, and bilaterally over the forearm, upper arm and hand, thighs, calves and feet (mid-segmental regions). The rigid bodies will be used to track segment movement during experimental testing. A static calibration will determine the relationship between the rigid bodies and the calibration markers over the anatomical landmarks, and subsequently joint centers and segment coordinate systems.

#### Pocket Radar

A radar gun will be used to measure ball velocity. Ball velocity will be recorded as the ball leaves your hand. The radar gun will be calibrated before a testing session.

#### Video Cameras

High speed video cameras (2) will capture the pitching motion. The first camera will be positioned orthogonally to the pitching rubber, to capture the front side of the body (on the right of the pitching rubber for right-handed pitchers, on the left for the left-handed pitchers). The second camera will be positioned at a 20 degree angle with respect to the pitching rubber, behind the pitcher (Figure 1). This will simulate the camera angle often used during major league baseball broadcasts.



**Figure 1:** Position of high speed video cameras with respect to the pitcher during data collection.

#### **Data Analysis:**

Using motion capture technology, we will quantify your pitching mechanics, analyzing your joint postures, joint forces, and muscle activation levels throughout your pitching motion. The video of your pitching session will be

anonymized (your face blurred or obscured), then analyzed by pitching experts using a new tool that can quantify pitching mechanics. A report of your mechanics can be e-mailed to you after the experiment is complete.

**Eligibility:** For the study, you will need to be right handed, over the age of 18. You should not have any upper extremity injuries in the past year that kept you from participating in OUA baseball.

**Timeline:** You will throw both fastballs and curveballs, in blocks of 5 pitches (5 fastballs, followed by 5 curveballs). You can take as much time between pitches as you require to prevent any fatigue from accumulating. The pitching session will end when you reach your 30-pitch limit, or when you feel you can no longer continue because of fatigue or discomfort. We anticipate you being in the laboratory for 1.5 hours (including set up and removal of the markers/electrodes).

### **POTENTIAL BENEFITS AND RISKS**

The primary benefit to you for participating in this study will be that it will expose you to the research environment and also to a number of different research technologies. This is of importance given that some of the participants will likely be kinesiology students who will be learning about the techniques in the classroom, thus gaining practical experience. At the end of the testing session, you will be given an opportunity for 'debriefing' where one of the researchers will answer any questions you may have about the protocol or results obtained during your data collection session. You will learn a little about baseball, specifically pitching, biomechanics and ergonomics.

There may be minimal risk associated with this study. For instance, the use of electromyography may require tape to secure the electrodes to the skin. However, in the unlikely event there is irritation caused by surface electrodes, this will fade in 1-2 days. We require to shave the locations prior to electrode placement to improve the quality of our recording sites. A single-use, disposable razor will be used and if bleeding or razor burn occurs, this will become the priority, rather than continuing the protocol. As a requirement for electromyography investigations, maximal voluntary exertions are required and mild muscle soreness may be a result of it. The pitching motion is a very dynamic and full body exercise, thus when done at high effort, you may feel soreness as a result. Additionally, you may experience delayed onset muscle soreness (DOMS) 24-48 hours' post experimentation.

In the very unlikely event of injury (for example, you may experience discomfort to the hand or forearm), we encourage any individuals with persistent irritation or discomfort to please visit the Campus Wellness Centre or your healthcare provider.

### **CONFIDENTIALITY**

Your identity will be kept confidential and only made available to the researchers. You will be identified only by a subject identification code during the data collection phase of this study. All data, including written records and electronic data, will be placed in a locked cabinet or stored on a secured computer in the locked office of the principal investigator. Data will be originally recorded on a computer that is password protected and only available to the researcher's in a locked and secure room. The data will remain at this institution. The data will not be linked with any other data set and the data will not be sent outside of the institution where it is collected. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Data will be kept until publication of the results, this can sometimes take 1-2 years. After this time, all subject identification codes will be removed from the data and kept indefinitely.

Access to this data will be restricted to Dr. Holmes and the graduate student involved in this work.

### **VOLUNTARY PARTICIPATION**

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. If you are a Brock student, withdrawing from the study will in no way affect your academic standing. If you wish to withdraw during a study, simply tell the investigator that you no longer wish to participate. Participation, non-participation or withdrawal from the study will not affect

one's standing at Brock University. If you are a student of the PI, recruitment will be handled by a third-party individual to avoid real or perceived coercion that you may feel.

**COMPENSATION FOR PARTICIPATION**

You will be reimbursed for participation with a \$5 Tim Hortons gift card. If you withdraw halfway through the study and can no longer complete the session, you will still be reimbursed.

**PUBLICATION OF RESULTS**

Results of this study may be published in professional journals and presented at conferences. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Feedback about this study will be available to you by contacting Dr. Holmes at the address at the top of the form. Results should be made available approximately 6 months after your completion of the study. The results will be group data about the main findings of the study. If you wish to know more about individual data, we can arrange to meet.

**CONTACT INFORMATION AND ETHICS CLEARANCE**

If you have any questions about this study or require further information, please contact Dr. Holmes using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (File # \_\_\_\_\_). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, [reb@brocku.ca](mailto:reb@brocku.ca).

Thank you for your assistance in this project. Please keep a copy of this form for your records.

**CONSENT FORM**

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: \_\_\_\_\_

Signature: \_\_\_\_\_

## Informed Consent

**Michael W.R. Holmes**, PhD  
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Date: February 22, 2018  
Project Title: Development of a Novel Pitching Mechanics Tool

Principal Investigator (PI): Michael Holmes, Assistant Professor  
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[michaelsonne@gmail.com](mailto:michaelsonne@gmail.com)

### INVITATION

You are invited to participate in a research study. Numerous studies have identified overuse, high velocities, lack of rest time, and high workloads as root causes for musculoskeletal pitching injuries. It is an epidemic affecting pitchers at all age levels. Despite the reduction of elbow surgery cases over the past two seasons, the concern for a pitcher’s health still exists. Of all these risk factors, the most difficult to measure are the mechanics of a pitcher during a throwing motion. While improper pitching mechanics may lead to injuries, correcting them would not only improve health and decrease injury risk, but it would make you as the pitcher more effective on the mound. The purpose of this study is to develop an inexpensive tool which can allow for the rapid assessment of a pitcher’s biomechanics, and to establish the inter and intra-rater reliability of the tool.

### WHAT’S INVOLVED

As a pitching coach, baseball scout, or baseball analysts with at least five years’ experience working with or studying pitchers at a university-aged level (over age 17), you will be asked to evaluate an two separate images of a pitcher at lead foot strike, and assess the pitching mechanics of university-aged pitchers using the Pitching Mechanics Tool.

### EXPERIMENT PROTOCOL

You will be among the six pitching coaches, baseball scouts, or analysts with at least five years’ experience working with, or studying pitchers at a university-aged level (over age 17). You will access the Pitching Mechanics Tool online in Google Forms and be able to complete the sessions at your own time.

### Day 1:

Previously collected kinematic data from pitchers will be analyzed, and the hardest fastball throw for each pitcher will be selected for further analysis.

Using the two different camera images (rear and open side) provided of each of the 11 pitchers at lead foot strike, you as the evaluator will be responsible with selecting the most representative posture for each joint, for each pitcher. For each pitcher, you will access 16 body segments and select the most appropriate posture that best represents the throw. After the first 2 pitchers you assess, you will be able to view your results and get feedback to see how you performed. Review this feedback prior to moving on. You will then perform three more blocks of assessments, resulting in a total of 11 pitchers assessed (2 with feedback, 9 without feedback).

Once you feel comfortable with the tool and the video system, you will evaluate the remaining 9 pitchers.

The instructions given to you will be as follows:

1. The Pitching Mechanics Tool will evaluate a pitcher's posture at the instance of lead foot strike.
2. Check off the postures, which are appropriate in the Tool. The experimenter cannot give you any feedback on your answers after the first two trial pitchers have been evaluated.
3. Take as much time answering each as necessary.

### Day 2 and 3:

The procedure from day 1 will be repeated two more times. This includes the evaluation of three practice pitchers, and providing feedback on the performance. The time between day 1, 2, and 3 will be a minimum of 2 days, and a maximum of 5 days.

#### Video Cameras

Video cameras (2) will capture the pitching motion from 11 pitchers in a previous study. You will be required to evaluate each pitch (Figure 1).

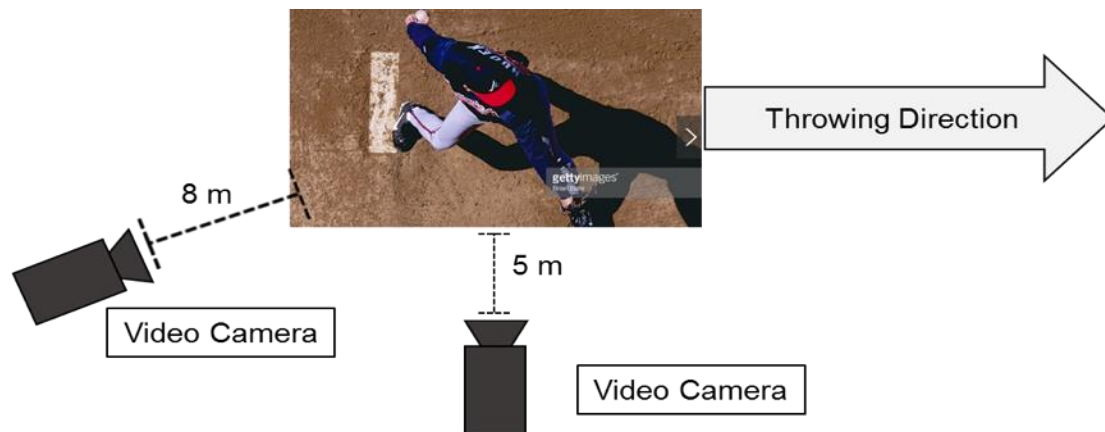


Figure 1: Position of high speed video cameras with respect to the pitcher during data collection.

#### Pitching Mechanics Tool

The exact tool is still under development. The Pitching Mechanics Tool will consist of static images of the hand, wrist, forearm, upper arm, trunk, and knee position during the lead foot strike of the baseball pitching motion. Posture ranges will be binned in appropriate degree increments as drawn from scientific literature. The user will

check off a box if the posture of the pitcher in the video is represented by the appropriate posture bins. An example of the Rapid Upper Limb Assessment (RULA) is included below (Figure 2). This is a very popular workplace assessment tool that is postural based. The Pitching Mechanics Tool will take a similar form.

**RULA Employee Assessment Worksheet** Based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

**A. Arm and Wrist Analysis**

**Step 1: Locate Upper Arm Position:**

Step 1a: Adjust...  
If shoulder is raised: +1  
If upper arm is abducted: -1  
If arm is supported or person is leaning: -1

**Step 2: Locate Lower Arm Position:**

Step 2a: Adjust...  
If either arm is working across midline or out to side of body: Add +1

**Step 3: Locate Wrist Position:**

Step 3a: Adjust...  
If wrist is bent from midline: Add +1

**Step 4: Wrist Twist:**  
If wrist is twisted in mid-range: +1  
If wrist is at or near end of range: +2

**Step 5: Look-up Posture Score in Table A:**  
Using values from steps 1-4 above, locate score in Table A

**Step 6: Add Muscle Use Score**  
If posture mainly static (i.e. hold-10 minutes),  
Or if action repeated occurs <5% per minute: -1

**Step 7: Add Force/Load Score**  
If load = 4-8 lbs (intermittent): +0  
If load 4-4 to 22 lbs (intermittent): +1  
If load 4-4 to 22 lbs (static or repeated): +2  
If more than 22 lbs or repeated or shocks: +3

**Step 8: Find Row in Table C**  
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in Table C.

**SCORES**

**Table A: Wrist Posture Score**

Upper Arm	Lower Arm	Wrist Twist			
		1	2	3	4
1	1	2	2	3	3
1	2	2	2	3	3
1	3	3	3	3	4
2	1	2	3	3	4
2	2	3	3	3	4
2	3	3	3	3	4
3	1	4	4	4	5
3	2	3	4	4	5
3	3	4	4	4	5
4	1	4	4	4	5
4	2	4	4	4	5
4	3	4	4	5	5
5	1	5	5	5	6
5	2	5	5	6	7
5	3	5	6	6	7
6	1	6	6	6	7
6	2	6	6	6	7
6	3	6	6	6	7

**Table B: Neck, Trunk and Leg Score**

Neck Posture	Legs		Legs		Legs		Legs	
	1	2	3	4	5	6	7	8
1	2	2	3	3	4	4	5	5
2	2	2	3	3	4	4	5	5
3	2	2	3	3	4	4	5	5
4	2	2	3	3	4	4	5	5
5	2	2	3	3	4	4	5	5
6	2	2	3	3	4	4	5	5
7	2	2	3	3	4	4	5	5
8	2	2	3	3	4	4	5	5

**Table C: Wrist and Arm Score**

Wrist and Arm Score	1	2	3	4	5	6	7	8
1	1	2	3	3	4	5	6	6
2	2	2	3	4	4	5	6	6
3	3	3	3	4	4	5	6	6
4	3	3	3	4	4	5	6	6
5	4	4	4	4	5	6	7	7
6	4	4	4	4	5	6	7	7
7	5	5	5	5	6	7	7	7
8	5	5	5	5	6	7	7	7

**Table D: Neck, Trunk and Leg Score**

Neck Posture	1	2	3	4	5	6	7	8
1	2	2	3	3	4	4	5	5
2	2	2	3	3	4	4	5	5
3	2	2	3	3	4	4	5	5
4	2	2	3	3	4	4	5	5
5	2	2	3	3	4	4	5	5
6	2	2	3	3	4	4	5	5
7	2	2	3	3	4	4	5	5
8	2	2	3	3	4	4	5	5

**Scoring: (final score from Table C)**  
1 or 2 = acceptable posture  
3 or 4 = further investigation, change may be needed  
5 or 6 = further investigation, change soon  
7 = investigate and implement change

**Step 9: Locate Neck Position:**

Step 9a: Adjust...  
If neck is twisted: +1  
If neck is side bending: +1

**Step 10: Locate Trunk Position:**

Step 10a: Adjust...  
If trunk is twisted: +1  
If trunk is side bending: +1

**Step 11: Legs:**  
If legs and feet are supported: +1  
If not: -2

**Step 12: Look-up Posture Score in Table B:**  
Using values from steps 9-11 above, locate score in Table B

**Step 13: Add Muscle Use Score**  
If posture mainly static (i.e. hold-10 minutes),  
Or if action repeated occurs <5% per minute: -1

**Step 14: Add Force/Load Score**  
If load = 4-8 lbs (intermittent): +0  
If load 4-4 to 22 lbs (intermittent): +1  
If load 4-4 to 22 lbs (static or repeated): +2  
If more than 22 lbs or repeated or shocks: +3

**Step 15: Find Column in Table C**  
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in Table C.

**Task name:** \_\_\_\_\_ **Reviewer:** \_\_\_\_\_ **Date:** \_\_\_\_/\_\_\_\_/\_\_\_\_

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in RULA. © 2004 Rose Consulting, Inc. rbarber@rosesmart.com (816) 444-1667

**Figure 2:** The Rapid Upper Limb Assessment (McAtamney & Corlett, 1993). The Pitching Mechanics Tool will feature a similar system, where users will check off which posture is applicable to the video of the pitcher they are watching. Risk levels will be assigned at a later date.

**Timeline:** Each session should take no more than 45 minutes to complete.

**POTENTIAL BENEFITS AND RISKS**

The primary benefit to you in this study will be that it will expose you to the research environment and also to a number of different research technologies. At the end of the session, you will be given an opportunity for ‘debriefing’ where one of the researchers will answer any questions you may have about the protocol or results obtained in the data collection session. You will learn a little about baseball, specifically pitching, biomechanics and ergonomics.

For the evaluators, be it the coaches, scouts, or pitching analysts, there are no inherent risks.

**CONFIDENTIALITY**

Your identity will be kept confidential and only made available to the researchers. You will be identified only by a subject identification code during the data collection phase of this study. All data, including written records and electronic data, will be placed in a locked cabinet or stored on a secured computer in the locked office of the principal investigator. Data will be originally recorded on a computer that is password protected and only available to the researcher’s in a locked and secure room. The data will remain at this institution. The data will not be linked with any other data set and the data will not be sent outside of the institution where it is collected. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Data will be kept until publication of the results, this can sometimes take 1-2 years. After this time, all subject identification codes will be removed from the data and kept indefinitely.

Access to this data will be restricted to Dr. Holmes and the graduate student involved in this work.

**VOLUNTARY PARTICIPATION**

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. If you are a Brock student, withdrawing from the study will in no way affect your academic standing. If you wish to withdraw during a study, simply tell the investigator that you no longer wish to participate. If you wish to withdraw between sessions, simply contact the principal investigator. Participation, non-participation or withdrawal from the study will not affect one’s standing at Brock University. If you are a student of the PI, recruitment will be handled by a third-party individual to avoid real or perceived coercion that you may feel.

**COMPENSATION FOR PARTICIPATION**

You will be reimbursed for participation with a gift card for each session. If you withdraw halfway through a session and can no longer complete the session, you will still be reimbursed.

**PUBLICATION OF RESULTS**

Results of this study may be published in professional journals and presented at conferences. Any images and videos we release publicly will remain confidential by blurring out any identifying factors of any of the participants involved. This includes the blurring of participants faces. Feedback about this study will be available to you by contacting Dr. Holmes at the address at the top of the form. Results should be made available approximately 6 months after your completion of the study. The results will be group data about the main findings of the study. If you wish to know more about individual data, we can arrange to meet.

**CONTACT INFORMATION AND ETHICS CLEARANCE**

If you have any questions about this study or require further information, please contact Dr. Holmes using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (File #18-120). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, [reb@brocku.ca](mailto:reb@brocku.ca).

Thank you for your assistance in this project.

**CONSENT FORM**

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: \_\_\_\_\_

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Appendix D – Data Screening Form

**Neuromuscular Mechanics and Ergonomics Laboratory  
Participant screening/participation form**

---

Subject ID \_\_\_\_\_  
Date of Birth \_\_\_\_\_  
Date \_\_\_\_\_

**Questions:**

1. Male or Female? (circle)
  
2. Age: \_\_\_\_\_
  
3. Previous upper extremity injury? Yes / No (circle)

**If Yes, please identify (list) any injuries that you have had in the past 12 months and when it occurred (e.g. sprained wrist, 2 months ago):**

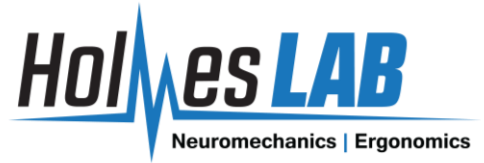
**Some examples may include, but are not limited to: muscle strain/sprain, ligament strain/strain, bone/joint pain, neurological impairments, etc.**

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## Neuromechanics and Ergonomics Laboratory

Baseball pitchers deal with the constant fear of injury each and every season. Our goal is to alleviate that fear. Our study focuses on evaluating pitching mechanics on the mound with state of the art technology available in our lab.

- **We are looking for OUA-aged pitchers (at least 18 years of age) with no major baseball-related injuries in the past year.**
- **Non-invasive measures of muscle activity (electromyography) and motion capture will be used.**
- **Participants will be required to make 1 visit to the NEUROMECHANICS AND ERGONOMICS LAB at Brock University (TH 141).**

You will be asked to throw 30 pitches (15 fastballs and 15 curveballs) off an indoor mound into a pitching net. Using our pitching mechanics tool, we will have a panel of experienced baseball coaches and scouts evaluate each participant. Your pitching session will be video taped for the coaches to evaluate.

***In appreciation for your time, you will be reimbursed with a \$5 gift card.***

For more information about this study, or to volunteer, please contact:

Richard Birfer, MSc. Candidate  
Brock University | Department of Kinesiology  
Niagara Region | 1812 Sir Isaac Brock Way | St. Catharines, ON L2S 3A1  
Phone: 5198511433 | Email: [rb17yq@brocku.ca](mailto:rb17yq@brocku.ca)



## Appendix F – Visual 3D Kinematic Analysis Results

- Joint Angles (°)

	Bins			
THROWING ARM	Subject 1 (FB15) - Frame 171	Subject 2 (FB12) - Frame 327	Subject 3 (FB2) - Frame 496	Subject 4 (FB1) - Frame 1315
Elbow Flexion	64.428	76.687	63.274	108.967
Forearm Pronation	-4.782	-4.221	-41.15	44.852
Horizontal Abduction	-28.494	-52.994	-34.155	-34.036
Shoulder Abduction	74.053	95.872	101.366	150.389
Shoulder External Rotation	130.955	125.788	153.026	180.053
Trunk Rotation	76.967	97.904	67.61	91.609
Trunk Lateral Tilt (X)	0.858	-12.373	-29.031	-2.575
Trunk Forward Flexion (Y)	9.919	-15.392	-5.951	-12.517
Pelvis Rotation	29.404	38.694	27.183	45.06
Lead Knee Extension	121.201	118.197	128.787	139.9
Lead Foot Rotation	204	200.87	163.427	193.568
Foot Strike	Flat	Heel Strike	Flat	Heel Strike
<b>GLOVE ARM</b>				
Elbow Flexion	81.868	77.701	80.911	123.511
Shoulder External Rotation	11.179	13.681	56.315	29.897
Shoulder Abduction	79.072	87.058	46.836	94.095
Shoulder Horizontal Abduction	-60.624	-68.087	-35.634	-53.722

	Bins			
THROWING ARM	Subject 5 (FB15) - Frame 393	Subject 6 (FB7) - Frame 1015	Subject 7 (FB5) - Frame 448	Subject 8 (FB3) - Frame 337
Elbow Flexion	60.064	84.67	65.615	81.244
Forearm Pronation	18.032	-32.93	-2.89	-12.354
Horizontal Abduction	-19.596	-41.043	-31.316	-9.012
Shoulder Abduction	101.718	89.784	96.329	92.559
Shoulder External Rotation	109.806	118.564	128.398	142.727
Trunk Rotation	79.772	83.984	72.794	63.706
Trunk Lateral Tilt (X)	-9.73	2.377	-18.901	-17.966
Trunk Forward Flexion (Y)	17.043	19.809	-0.422	1.831
Pelvis Rotation	39.93	41.213	17.255	-1.799
Lead Knee Extension	117.225	137.643	128.274	123.738
Lead Foot Rotation	202.283	176.725	169.408	147.274
Foot Strike	Heel Strike	Toe Strike	Toe Strike	Toe Strike
<b>GLOVE ARM</b>				
Elbow Flexion	93.731	76.75	124.409	122.503
Shoulder External Rotation	10.549	22.498	38.996	69.667
Shoulder Abduction	68.013	53.261	66.226	76.224
Shoulder Horizontal Abduction	-37.096	-46.535	-53.059	-51.065

	Bins		
THROWING ARM	Subject 9 (FB6) - Frame 859	Subject 10 (FB14) - Frame 715	Subject 11 (FB8) - Frame 664
Elbow Flexion	94.651	107.309	67.236
Forearm Pronation	-22.019	-40.568	-15.023
Horizontal Abduction	-35.155	-30.907	-5.54
Shoulder Abduction	91.445	55.213	79.007
Shoulder External Rotation	133.009	168.798	144.6
Trunk Rotation	64.238	53.206	51.642
Trunk Lateral Tilt (X)	7.794	-10.845	-16.129
Trunk Forward Flexion (Y)	8.767	-10.416	1.808
Pelvis Rotation	21.593	11.543	9.04
Lead Knee Extension	125.775	116.003	115.091
Lead Foot Rotation	147.173	162.541	164.162
Foot Strike	Toe Strike	Toe Strike	Toe Strike
<b>GLOVE ARM</b>			
Elbow Flexion	87.985	110.191	133.29
Shoulder External Rotation	34.672	43.83	55.199
Shoulder Abduction	82.706	68.781	65.219
Shoulder Horizontal Abduction	-55.349	-40.074	-59.552

- Bins

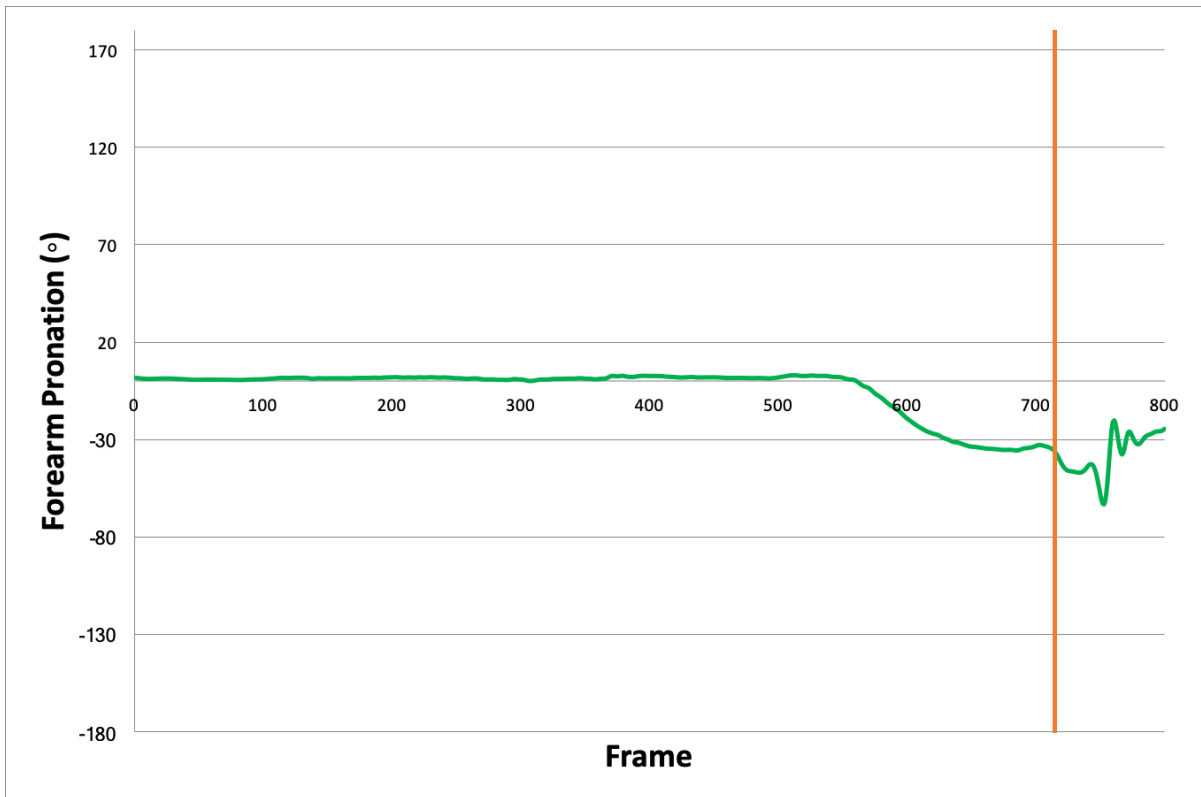
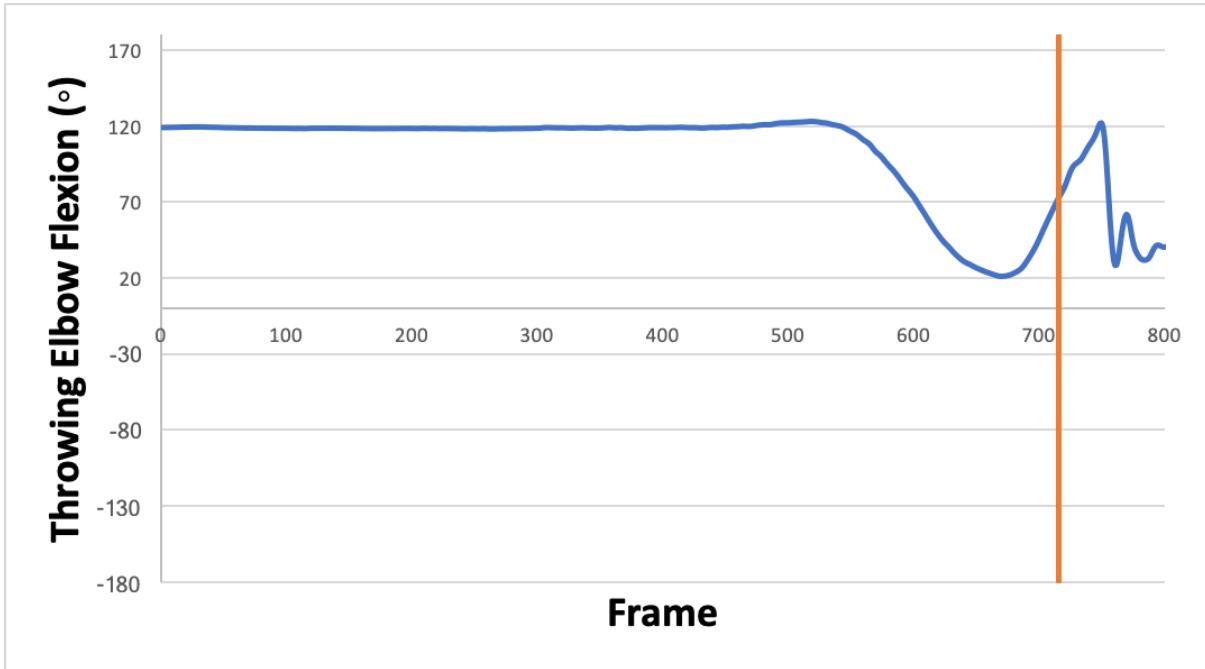
	Bins			
THROWING ARM	Subject 1 (FB15) - Frame 171	Subject 2 (FB12) - Frame 327	Subject 3 (FB2) - Frame 496	Subject 4 (FB1) - Frame 1315
Elbow Flexion	2	3	2	3
Forearm Pronation	2	2	2	2
Horizontal Abduction	2	1	2	1
Shoulder Abduction	1	2	2	3
Shoulder External Rotation	3	3	3	3
Trunk Rotation	2	3	2	3
Trunk Lateral Tilt (X)	2	1	1	2
Trunk Forward Flexion (Y)	3	1	1	1
Pelvis Rotation	2	2	2	2
Lead Knee Extension	3	1	2	2
Lead Foot Rotation	4	4	2	3
Foot Strike	3	3	2	3
<b>GLOVE ARM</b>				
Elbow Flexion	3	3	3	4
Shoulder External Rotation	3	3	3	3
Shoulder Abduction	1	2	1	2
Shoulder Horizontal Abduction	1	1	1	1

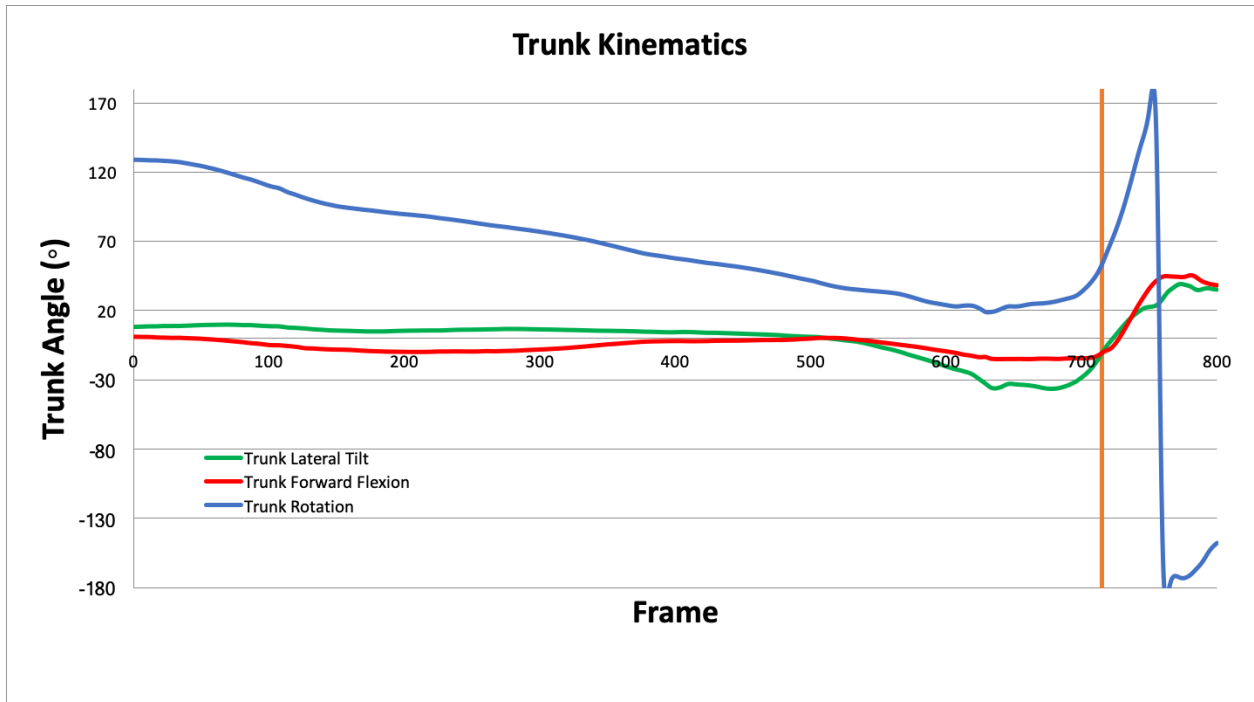
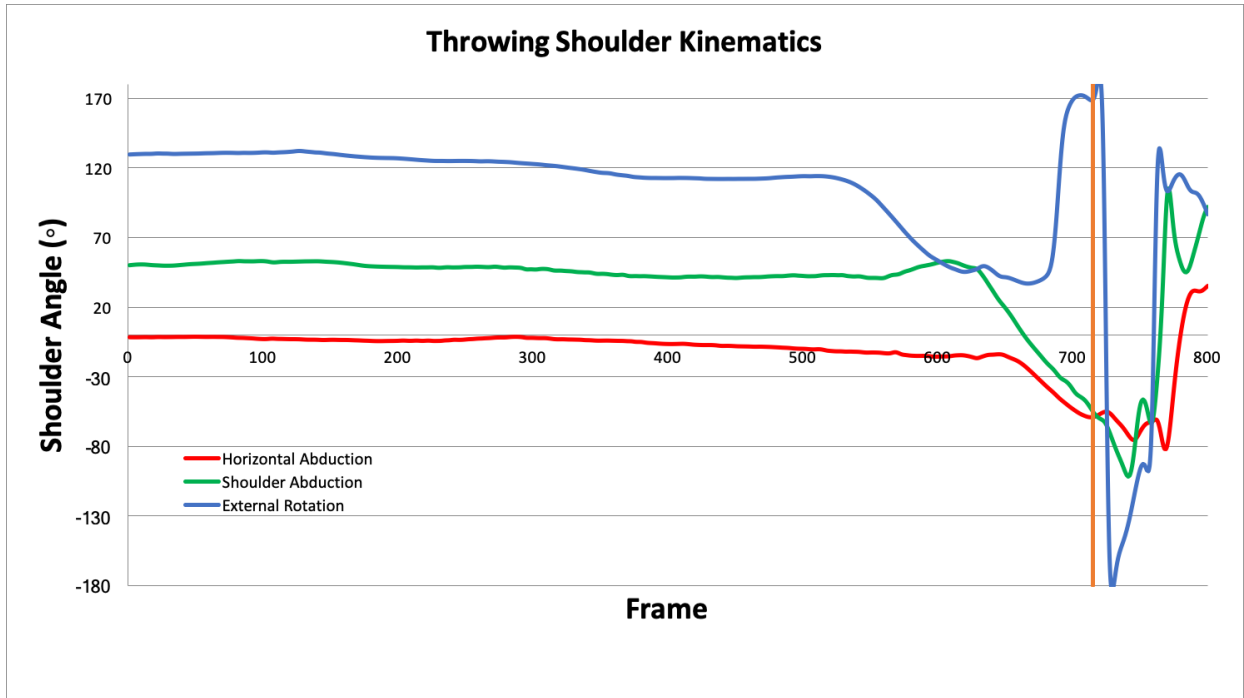
	Bins			
THROWING ARM	Subject 5 (FB15) - Frame 393	Subject 6 (FB7) - Frame 1015	Subject 7 (FB5) - Frame 448	Subject 8 (FB3) - Frame 337
Elbow Flexion	2	3	2	2
Forearm Pronation	2	2	2	2
Horizontal Abduction	2	1	2	3
Shoulder Abduction	2	2	2	2
Shoulder External Rotation	2	2	3	3
Trunk Rotation	2	3	2	2
Trunk Lateral Tilt (X)	1	2	1	1
Trunk Forward Flexion (Y)	3	3	1	3
Pelvis Rotation	2	2	1	1
Lead Knee Extension	3	2	2	2
Lead Foot Rotation	4	3	1	2
Foot Strike	3	1	1	1
<b>GLOVE ARM</b>				
Elbow Flexion	3	3	4	4
Shoulder External Rotation	1	1	1	2
Shoulder Abduction	1	1	1	1
Shoulder Horizontal Abduction	1	1	1	1

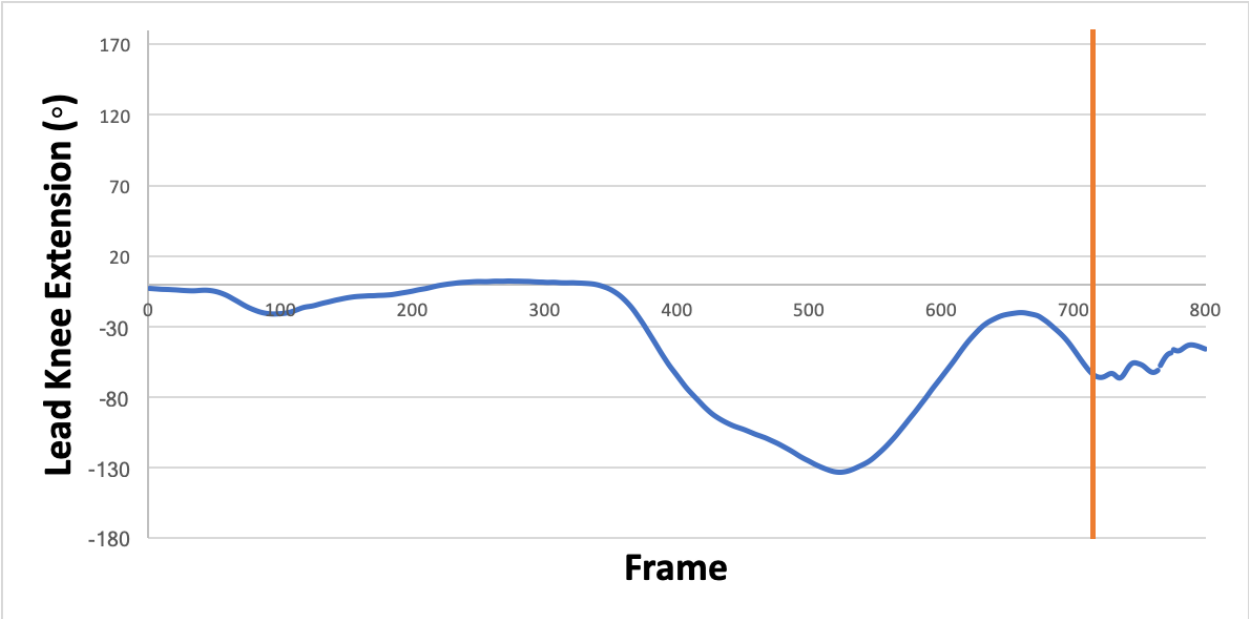
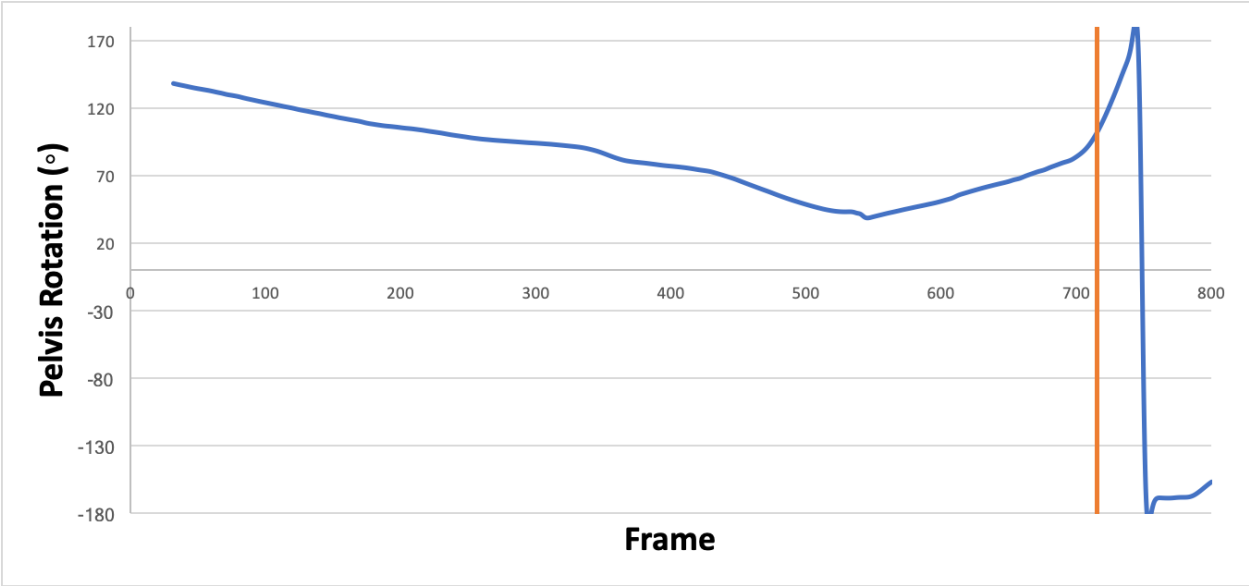
	Bins		
THROWING ARM	Subject 9 (FB6) - Frame 859	Subject 10 (FB14) - Frame 715	Subject 11 (FB8) - Frame 664
Elbow Flexion	3	3	2
Forearm Pronation	2	2	2
Horizontal Abduction	1	2	2
Shoulder Abduction	2	1	1
Shoulder External Rotation	3	3	3
Trunk Rotation	2	1	2
Trunk Lateral Tilt (X)	2	1	2
Trunk Forward Flexion (Y)	1	1	3
Pelvis Rotation	1	1	2
Lead Knee Extension	2	3	3
Lead Foot Rotation	1	2	4
Foot Strike	1	1	1
<b>GLOVE ARM</b>			
Elbow Flexion	3	3	3
Shoulder External Rotation	1	1	1
Shoulder Abduction	1	1	1
Shoulder Horizontal Abduction	1	1	1

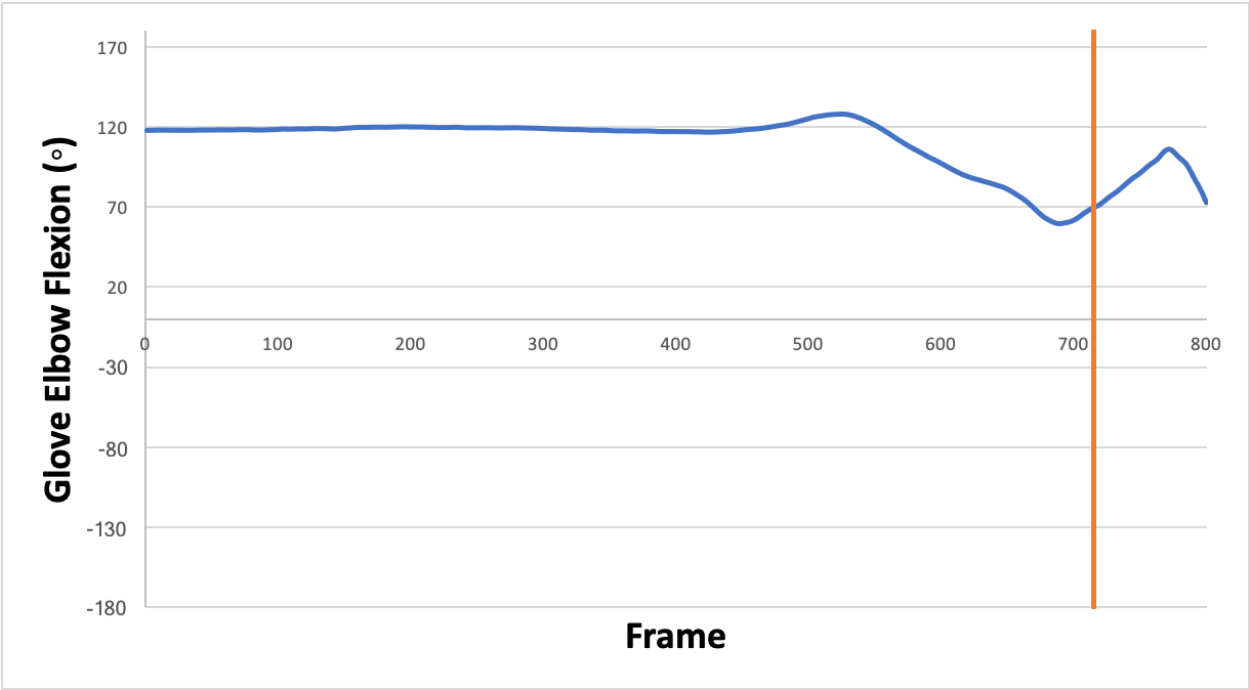
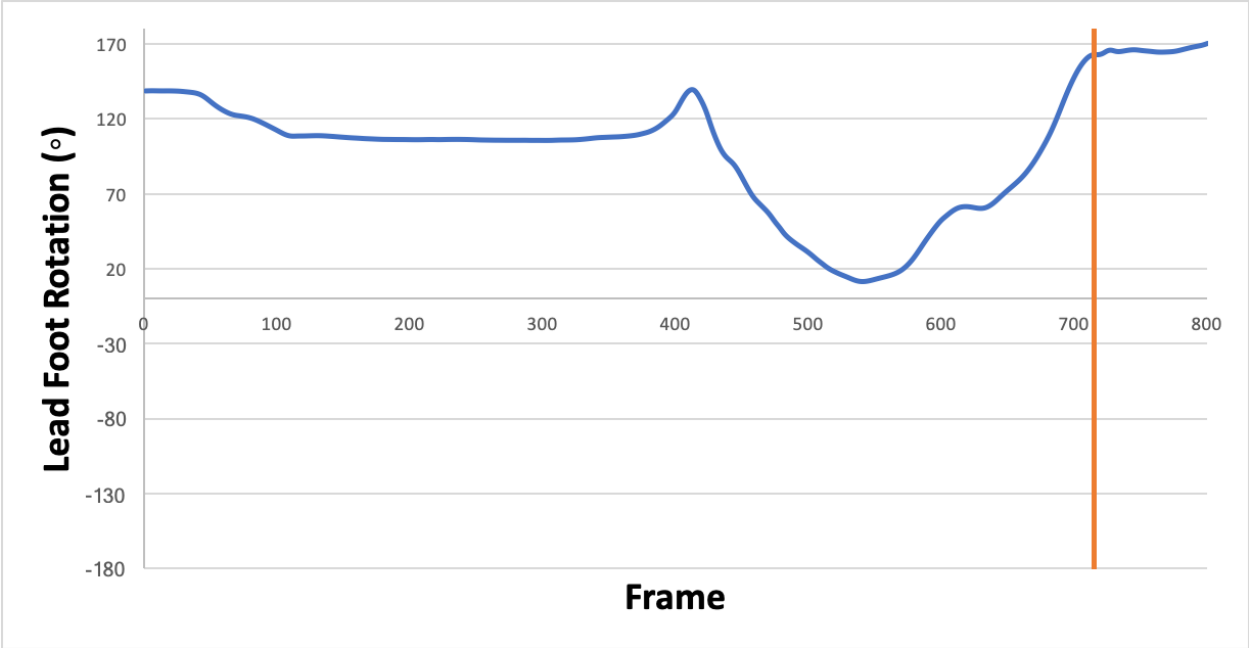
Appendix G – Visual 3D Developed Joint Angle Graphs

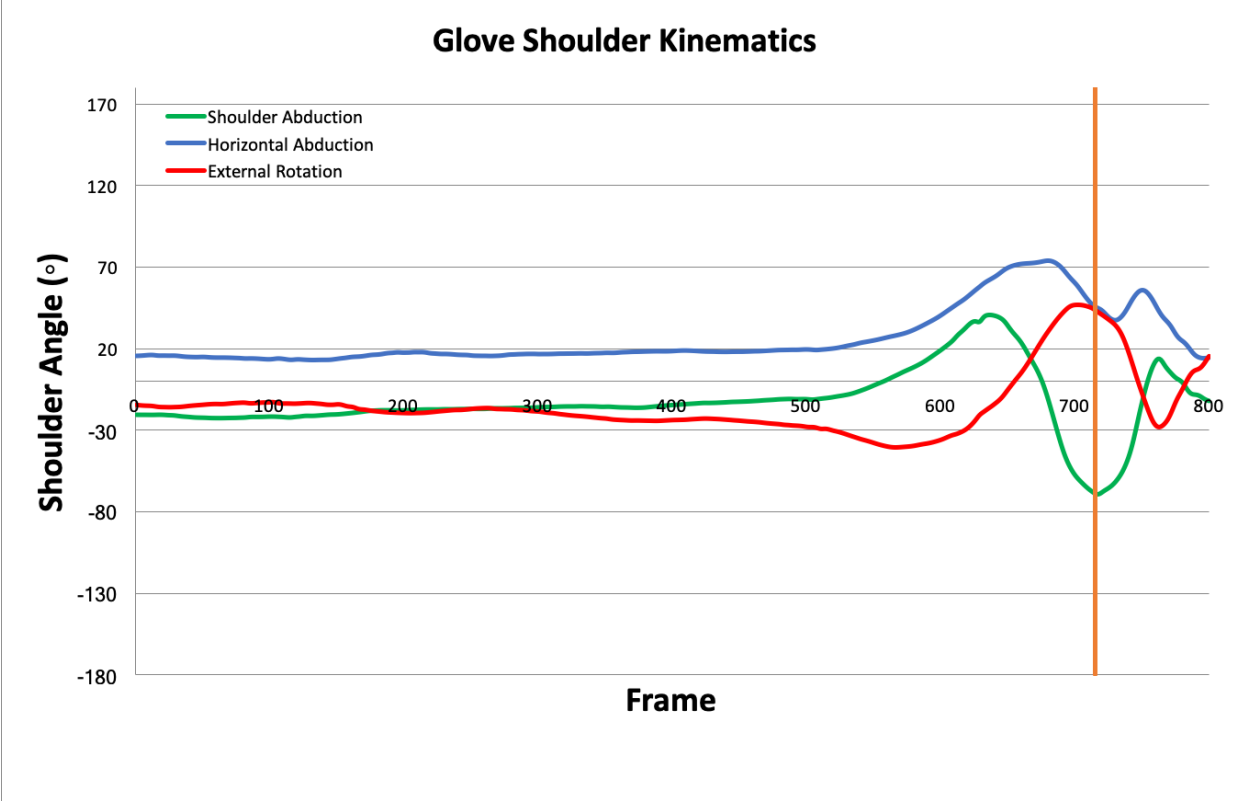
- Vertical orange line signifies moment of lead foot strike\*













## Appendix H – Printable Version of the Pitching Mechanics Tool

**Pitching Mechanics Tool**

Pitcher Name: \_\_\_\_\_

Evaluator: \_\_\_\_\_

Date: \_\_\_\_\_



**Instructions:** The PMT is designed to evaluation pitcher kinematics at the instance of front foot strike. Record video of a pitcher throwing off of a mound, preferably at greater than 60 frames per second (for best results). Freeze the video at the moment any contact is made between the front foot, and the ground, and estimate the range for each of the 16 parameters contained within this tool.

**Throwing Arm**

Segment 1. Elbow Flexion	Segment 2. Forearm Pronation	Segment 3. Horizontal Abduction	Segment 4. Shoulder Abduction	Segment 5. External Rotation
<input type="checkbox"/> < 55°	<input type="checkbox"/> Supinated	<input type="checkbox"/> < -35°	<input type="checkbox"/> < 83°	<input type="checkbox"/> Inverted W
<input type="checkbox"/> 55° to 74°	<input type="checkbox"/> Neutral	<input type="checkbox"/> -35° to -13°	<input type="checkbox"/> 83° to 102°	<input type="checkbox"/> Neutral
<input type="checkbox"/> 74° to 111°	<input type="checkbox"/> Pronated	<input type="checkbox"/> > 13°	<input type="checkbox"/> > 102°	<input type="checkbox"/> Arm Up
<input type="checkbox"/> 112° to 130°				
<input type="checkbox"/> > 130°				
Segment 6. Trunk Rotation	Segment 7. Trunk Lateral Tilt	Segment 8. Trunk Forward Flexion	Segment 9. Pelvis Rotation	
<input type="checkbox"/> < 56°	<input type="checkbox"/> < -5°	<input type="checkbox"/> Extension	<input type="checkbox"/> < 23°	
<input type="checkbox"/> 56° to 82°	<input type="checkbox"/> -5° to 8°	<input type="checkbox"/> Neutral	<input type="checkbox"/> 23° to 49°	
<input type="checkbox"/> > 82°	<input type="checkbox"/> > 8°	<input type="checkbox"/> Flexion	<input type="checkbox"/> > 49°	

This tool was produced and is owned by Richard Birfer, Michael Sonne, and Michael Holmes. Use of the PMT is freely acceptable, but please cite Birfer, Holmes and Sonne, 2019, when referring to the tool. For additional information on the PMT, please contact Michael Sonne – [michaelsonne@gmail.com](mailto:michaelsonne@gmail.com), or @DrMikeSonne on Twitter.

**Pitching Mechanics Tool**

Pitcher Name: \_\_\_\_\_

Evaluator: \_\_\_\_\_

Date: \_\_\_\_\_



Segment 10. Lead Knee Extension

- < 143°
- 123° to 143°
- > 123°

Segment 11. Lead Foot Rotation

- Closed
- Angled
- Home
- Open

Segment 12. Lead Foot Strike

- Toe Strike
- Flat
- Heel Strike

Segment 16. Horizontal Abduction

- < -35°
- 35° to -13°
- > -13°

**Glove Arm**

Segment 13. Elbow Flexion

- < 55°
- 55° to 74°
- 74° to 111°
- 112° to 130°
- > 130°

Segment 14. External Rotation

- Inverted W
- Flat Arm
- Arm Up

Segment 15. Shoulder Abduction

- < 83°
- 83° to 102°
- > 102°

The PMT can be completed at any time during practice or games, used to track the effects of fatigue and performance changes as result of training. For more information on the PMT, follow @richardbirfs, @DrMikeSonne, and @HolmesLab on Twitter.

This tool was produced and is owned by Richard Birfer, Michael Sonne, and Michael Holmes. Use of the PMT is freely acceptable, but please cite Birfer, Holmes and Sonne, 2019, when referring to the tool. For additional information on the PMT, please contact Michael Sonne – [michaelsonne@gmail.com](mailto:michaelsonne@gmail.com), or @DrMikeSonne on Twitter.