RELIABILITY OF A VISUAL OBSERVATION PITCHING ASSESSMENT IN ADOLESCENT PITCHERS

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ABSTRACT

Emily Quatromoni: Reliability of a Visual Observation Pitching Assessment in Adolescent Pitchers
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Pitching mechanical errors are potential risk factors for upper extremity injury in baseball pitchers. Creating a reliable assessment tool will allow coaches and sports medicine professionals to identify faulty pitching mechanics and correct these mechanics before injury occurs. The purpose of this study was to establish the intra- and inter-rater reliability of previously studied biomechanical errors that have been linked to injurious stresses. Each participant pitched a minimum of ten pitches that included a minimum of three strikes, while frontal and sagittal video was collected. Separate Cohen's kappa coefficients were used to establish reliability. Acceptable intra-rater reliability was established for all six biomechanical errors. Acceptable inter-rater reliability was established for three out of the six errors. This study lays the foundation for the development of a clinically applicable assessment tool which has the potential of identifying faulty pitching mechanics to decrease the injury associated with pitching.

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CHAPTER I: INTRODUCTION

Currently in the United States there are 11.5 million baseball players, with the majority of these players younger than age 18.[1] Over the past twenty years, adolescent participation in baseball has substantially increased. [2] While participation in athletics has its health benefits, it also has its health risks such as musculoskeletal injury. More than half of the musculoskeletal injuries seen in adolescent baseball athletes involve the upper extremity.[2] Of the 58% of upper extremity injuries that occur during baseball, 73% of shoulder injuries and 70% of elbow injuries occur during pitching.[3] Half of all pitchers experience upper extremity pain that prevents participation at some point in their career.[4]

It has been previously stated that faulty pitching mechanics are associated with injury.[5] Faulty pitching mechanics lead to repetitive, greater magnitude stress on the joints which may leave the soft tissue around the shoulder and elbow susceptible to damaging microtrauma.[5] To better understand the mechanics of pitching, the pitch is broken down into six phases. Phases include the windup, stride or early cocking, late cocking, acceleration, deceleration, and follow through.[6] Pitching errors are noted throughout the pitching motion. [7,8] However, the errors that occur during arm-cocking and arm-acceleration phases are considered particularly dangerous, because the loads placed on the shoulder and elbow joints are the highest during these phases.[7,8] Moreover, the errors that occur before or at the stride foot contact that may lead to the errors during the arm-cocking and acceleration phases may be potentially harmful to the joints.[7,8]

In order to prevent injurious stresses placed on the upper extremity during pitching, there is a need for a tool that allows coaches and clinicians to identify pitchers with high risk of injury. Currently, the only pitching assessment tool that is available in the literature is the one developed by the American Sports Medicine Institute, based on their large database of pitching trials. However, the assessment tool that consists of 24-point checklist of technical parameters that can be observed during the entire pitching motion has major limitations. [9] First, while most of the 24 technical parameters could be identified with relatively high reliability, the visual evaluation of the parameters had poor agreement with the quantitative data collected using the motion capture system. [9] Second, since the tool was not intended to identify pitchers with higher risk of injury, the evaluation of pitching technique using this scale does not predict loads placed on the joint, pitchers' risk of injury, or performance.[9]

More recently, in an attempt to identify visually identifiable pitching technical errors that may be predictive of injury risk, Davis *et al*[5] studied whether five technical parameters that they identified are associated with increased joint loading. Davis *et al*[5] found that if a pitcher between 9-13 years old demonstrated forearm supination as the hand comes out of the glove, open shoulder at stride foot contact, and one other parameter correctly then the pitcher would have decreased humeral internal rotation torque, decreased elbow valgus load, and increased pitching efficiency. A study by Oyama *et al*[8] also examined whether the technical parameters pertaining to pitcher's trunk movement are linked to increased joint loading, and demonstrated that excessive contralateral trunk lean at maximal humeral external rotation was linked to increased joint loading. This study also found that backward lean at stride foot contact and stride foot position at stride foot contact increased the likelihood that the pitcher would also demonstrate contralateral trunk lean.[8] The limitation of these studies, however, is that they did not report how reliably clinicians and coaches can identify these parameters.[5,8] Therefore, the purpose of this study was to establish the intra- and inter-rater reliability of previously studied biomechanical errors that have been proven to cause injurious forces at the elbow and shoulder. In order to develop a true clinical screening tool that could be predictive of injury risk in the future, it needs to be both valid and reliable.

The few studies that have previously quantified the effect of pitching errors on joint stress are novel and lay the foundation for the current study. The purpose of this study was to establish the intra- and inter-rater reliability of biomechanical errors that have previously been quantified to cause injurious stresses on the upper extremity. By establishing the reliability of these errors, we would then be able to create a time effective, clinically applicable and reliable assessment tool that would allow athletic trainers and other sports medicine professionals to determine faulty pitching mechanics. Additionally, an easy to use assessment would be beneficial for coaches to identify faulty pitching mechanics before injury occurs. To create such an assessment tool, more observable technical errors associated with increased joint loading must be identified and established as reliable.

Research Questions and Hypothesis

1. Establish the intra- and inter-rater reliability of a visual observation pitching assessment in adolescent pitchers.
    a. Hypothesis: We hypothesize that this assessment tool will have acceptable intra- and inter-rater reliability.

CHAPTER II: LITERATURE REVIEW

Adolescent Population

During 2006-2007, more than 7.3 million high school aged adolescents participated in athletics.[10] In 2010, 3 million adolescents participated in baseball alone.[10] The 3 million adolescent participants include Little League, middle school, and high school aged baseball players. The most common age of pitchers ranged from 9 to 18 years old.[11]

Incidence of Injury

Baseball is a relatively safe sport compared to some of America's other favorite sports, but with an increasing number of athletes participating in baseball comes an increasing number of injuries. During the 2005-2006 and 2006-2007 seasons, there was an injury rate of 1.89 injuries per 1000 athletes in competition exposures and 0.85 injuries per 1000 athletes in practice exposures.[12] Out of those injuries, 13.2% of all injuries were caused by pitching with 34.2% of these pitching injuries involving the shoulder and 18.9% involving the elbow.[12] Throughout 2005-2008, 1.72 injuries occurred for every 10,000 high school age athlete exposures, with pitching being the most common mechanism of injury.[10] Pitchers, who pitched over 100 innings during a season, were 3.5 times more likely to be injured.[13] With the increased number of innings pitched or competition exposures, it was found that adolescent pitchers have a 5% risk of sustaining a throwing injury within 10 years of the athletic career.[13]

The most commonly reported complaint is shoulder pain. Lyman *et al*[11] reported that 29% of shoulder pain cases involved the superior aspect of the shoulder, 20% involved the anterior aspect, 20% involved the posterior aspect, and 20% involved the lateral aspect. Ten percent of shoulder pain in pitchers occurred in more than one location.[11] Only two of these cases were diagnosed by a physician; one case was a muscle strain and the other was rotator cuff inflammation. The second most commonly reported complaint is elbow pain. Lyman *et al* [11] reported that elbow pain involving only the medial side was reported 68% of the time, while 27% of the time elbow pain was reported to involve the lateral side exclusively. Three of the elbow pain cases in the Lyman *et al*[11] study were physician diagnoses to be medial epicondylitis.

Pitching Mechanics

Instruction of proper pitching mechanics early in an athlete's career will help minimize the risk of injury and maximize performance.[14] A study completed by Fleisig *et al*[14] disclosed that pitching mechanics do not change significantly between levels of competition. The study evaluated youth, high school, college and professional baseball pitchers and concluded that adolescent pitchers should have their mechanics consistently corrected while building and maintaining strength as the body matures. To develop proper pitching mechanics, the athlete must be able to coordinate all muscle groups, including the trunk and lower extremity, to pitch at a high caliber.[15] The biomechanical errors we plan to look at in this study that should be corrected in adolescent pitchers are described during the phase they occur during and summarized in **Table 1.**

Windup Phase

The pitching motion begins with the pitcher's first movement from the static position, which is facing the batter with both feet on the rubber.[6] This phase is dependent on lower extremity power to achieve maximum knee height, as well as core stability to keep the athlete from losing balance.[6] When the athlete's lead leg reaches maximum knee height, the pitcher has reached the balance point, the point where the pitcher begins to remove the ball from his glove.[6] This phase sets up the timing for the remainder of the pitching motion and also has the lowest risk of injury.[6] Mechanics in this phase are considered faulty if there is poor balance at maximum lead knee height, premature forward movement towards home prior to reaching the balance point, and a high hand placement with shoulder in greater than ninety degrees of abduction.[6] If balance is not maintained, lower extremity neuromuscular control is decreased and can lead to further faulty mechanics in the later phases of the pitch.

The first of the errors that will be quantified during this study occurs immediately after the wind up phase ends and the early cocking phase begins. Forearm supination is characterized by the hand being under the ball as it comes out of the glove compared to a pronated position caused by the hand being on top of the ball as it comes out of the glove.[5] An increase of internal rotation torque is placed on the humerus and an increase of valgus load on the elbow has been associated with forearm supination.[5] An excess of horizontal abduction, or hyper-angulation, of the shoulder can also result from how the pitcher's hand comes out of the glove. Hyper-angulation has been associated with increase stress on that anterior shoulder.

Early Cocking Phase

During this phase, the athlete stores energy for use in the following phases of the pitch. From the motion of the lead leg reaching maximum knee height to the point when the lead foot has contact with the ground, the athlete's hips and torso rotate anteriorly (33 ±10°) as the throwing arm is abducted (93±11°) and externally rotated (56 ±22°).[6,16,17] The next four errors that we will be quantifying are open foot position, backward lean at stride foot contact, open shoulder, and the elbow not at maximum height at stride foot contact. All four of these errors occur during stride foot contact, which is when any part of the stride foot comes in contact with the ground.

Open foot position is characterized by the foot not being directed towards home plate at stride foot contact. This error is measured in degrees directed either towards first or third base.[5] Increased anterior force is placed upon the shoulder during early cocking phase if the foot is not directed towards home plate.[5] The next error, backward lean at stride foot contact, is characterized by the pitcher's head being behind the vertical line passing through the front of the ankle when the stride foot makes contact with the ground.[7] Pitchers, who demonstrated backward lean at stride contact, also demonstrated contralateral trunk lean at maximal shoulder external rotation.[7] Increased shoulder and elbow joint loading is not associated with backward lean at stride foot contact, but is associated with lateral trunk lean at maximal shoulder external rotation.[8] Since lateral trunk lean at maximal shoulder external rotation has been observed to follow backward lean at stride foot contact, it is important to quantify both errors.

Open shoulder is the fourth error we will be quantifying. Open shoulder is characterized by premature upper torso rotation where the anterior aspect of the shoulder faces the target instead of the lateral aspect.[5] Open shoulder increases elbow varus, which can lead to hyper-angulation of the shoulder and increase the stresses on the anterior shoulder.[5] To control horizontal abduction, horizontal adduction torque is applied.[16] This error has been associated with anterior instability, which can lead to shoulder injuries that include anterior shoulder dislocation and labral tears.[16] The fifth error, where the elbow does not reach maximum height (93±11◦), is characterized by not achieving the humeral elevation needed to achieve proper trunk rotation.[10,18] This error is associated with increases in shoulder hyper-angulation and the scapula placed in an unstable position if the humerus does not reach maximum height.

Late Cocking Phase

Once the lead foot contacts the ground, the arm reaches maximal abduction and external rotation.[16,19] When the arm is abducted and in external rotation, the position creates an anterior translational force of the humeral head upon the glenoid with internal rotational torques.[10,20] The greatest amount of shoulder internal rotation torque occurs near the time of maximal external rotation.[10]

The elbow reaches its greatest angle of flexion during this phase, (83.4±19.8°), which causes an increase of compressive forces across the radiohumeral and ulnohumeral joints.[16] Flexion, valgus, and pronation torques at the elbow reach their maximal values just before maximal external rotation of the humerus occurs.[16]

The last error to be quantified is contralateral trunk lean at maximum shoulder external rotation (MER). This error is defined by the pitcher's head deviating from the vertical line passing through the stride foot by more than a head's width.[7] Contralateral trunk lean at MER occurs during the late cocking phase and continues into the acceleration phase. This error has been associated with an increase in varus forces on the elbow and proximal forces on the shoulder.

Acceleration Phase

This phase begins at the point of maximal humeral external rotation. Increases in shoulder adduction, horizontal adduction and internal rotation torques are observed during this phase prior to ball release,[16] with the greatest overall amount of shoulder forces occurring near the time of ball release.[10] Decreased torque is observed throughout the remainder of the pitch.

Deceleration Phase

The deceleration phase is the shortest, but most dynamic phase. Once the ball is released, deceleration of the shoulder occurs through eccentric contraction of the posterior shoulder leading to forces at the shoulder joint equal to body weight. Additionally increased compressive forces directed posteriorly and eccentric loading of the rotator cuff muscles are seen during this phase.[10,21] Youth pitchers tend to experience difficulty during this phase due to underdeveloped internal rotators, specifically the teres minor.[16] This difficulty has been associated with a compensation of an increase in horizontal adduction across the torso.[16] The elbow reaches its greatest angle of extension (172.0± 4.5°) just after ball release.[16] This produces peak elbow compressive forces, where 60% of these forces are transferred across the radiohumeral joint.[16]

Follow Through Phase

Elbow and shoulder muscle activity during the follow through phase is decreased compared to the previous phases. The athlete must move quickly between the follow through phase of the pitch and fielding position in case the ball is hit back at him. The stance foot is completely off the ground and the trunk rotates toward home plate over the lead leg.[6] Internal rotation flexibility of lead hip allows the athlete to be able to achieve a balanced fielding position.[6] Acute injuries resulting from the ball being hit square back at the pitcher are more likely than ones caused by mechanics in this phase.[22,23]

Table 1. Planned Biomechanics Errors Assessed in Current Study

Phase	Error	Consequences
Between Wind up and Early Cocking	Forearm Supination at full elbow extension	Increases shoulder internal rotation torque and elbow valgus load. Can lead to excess shoulder horizontal abduction (hyper-angulation) of the shoulder
Between Early Cocking and Late Cocking	Open/Closed Foot Position	Increases the anterior force on the shoulder
	Backward Lean at SFC	Increase shoulder and elbow joint loading
	Open Shoulder	Increases elbow varus, which leads to hyper-angulation of the shoulder. Increases the stress on the anterior shoulder
	Decreased Trunk to Elbow Angle at SFC	Increases shoulder hyper-angulation. The scapula is placed in an unstable position if the humerus does not reach max height. (93±11◦)[17]
Between Late Cocking and Acceleration	Contralateral Trunk Lean at Maximal Shoulder External Rotation	Increases elbow varus and proximal forces on the shoulder

Etiology of Upper Extremity Pain

The factors that cause injury can be placed into one of two categories: intrinsic and extrinsic. Intrinsic factors cause stresses from within the body while extrinsic factors are external stresses from outside of the body. Examples of intrinsic factors of injury related to the upper extremity are scapula dysfunction and muscle imbalances. Scapula dyskinesis has been associated with rotator cuff injury.[24] Normal movement of the scapula involves upward rotation and posterior tilting during humeral elevation, but if this movement becomes impaired, it can cause rotator cuff impingement.[24] Rotator cuff impingement is most likely to occur during maximal external rotation.[17] This is one of the reasons why lateral trunk lean at maximal external rotation is being quantified in this study.

Examples of extrinsic factors of injury include lack of rest and recovery, increased number of pitches thrown, and types of pitches thrown. The mechanics of the pitch have been proven to be affected by the number of pitches thrown and the number of innings pitched.[10] The fatigue from these factors cause changes in the athlete's pitching mechanics and these changes have been associated with increased risk of injury.[10] The joint forces and torques that are created during the pitch, increase with the level of competition, and are associated with greater muscle strength.[14] These greater joint forces and torques have been associated with greater shoulder and elbow angular velocities which are produced by higher level pitchers during the arm cocking and acceleration phases.[14] Although these forces and torques are greater in higher level pitchers, the amount of force needed to cause injury is proportional to muscle mass and tissue strength.[14] Therefore, injuries caused by faulty pitching mechanics can occur at any level of competition.

Variability in mechanics from pitch to pitch is greatest in youth pitchers even though variability in mechanics is insignificant throughout all levels of competition.[25] Therefore, adolescents need to be instructed consistently about proper mechanics, so that they can continue these mechanics throughout their career. The fastball has been proven to produce greater torque compared to any of the other types of pitches in all age groups in both the elbow and shoulder joints.[18,20,26] Despite this finding, increased risk for injury in pitchers is due to volume of pitches during the game and season, fatigue, and poor mechanics rather than pitch type.[26,27] Various types of injuries due to poor pitching mechanics are described below.

Shoulder Impingement

There are two major types of shoulder impingement: primary and secondary. While primary impingement is more common in adults, secondary, or internal, impingement affects adolescent pitchers.[2] Secondary impingement occurs when the articular side of the supraspinatus tendon and the greater tuberosity become compressed against the posteriosuperior aspect of the glenoid rim and labrum during extremes of humeral abduction and external rotation.[15] These extremes tend to occur between the early cocking and acceleration phases.[15,16] There are three errors that lead to increased humeral abduction and one error that occurs during maximal shoulder external rotation. Forearm supination as the hand comes out of the glove, open shoulder position, and decreased trunk to elbow angle at SFC can lead to hyper-angulation of the shoulder while contralateral trunk lean at maximal shoulder external rotation causes an increase of proximal forces on the shoulder. The population of athletes that is susceptible to this injury normally has atraumatic microinstability of the glenohumeral joint and weak rotator cuff muscles.[15] These athletes tend to have complaints of pains during the early cocking, late cocking and/or acceleration phases of the pitch.[10]

Treatment for this type of injury does not necessarily include surgery. Most athletes can recover from internal impingement by being consistent with strengthening their dynamic and scapular stabilizers. Time loss for internal impingement varies.

Glenoid Labral Tears

Glenoid labral tears are less common in adolescent pitchers than in adults.[28] Pitchers between the ages of 13 and 15 years old had a 5.2% incidence of superior labrum anterior posterior (SLAP) injury.[29] However, a type II SLAP lesion, where the biceps labral anchor is detached from the superior aspect of the glenoid, is the most common type of labral tear in pitchers.[15] Labral tears are caused by an altered position of humeral rotation on the glenoid, which causes increased shear stresses on the superior labrum.[15] An athlete is at risk for a SLAP tear when the long head of the biceps tendon becomes compromised during maximal shoulder external rotation or when the shoulder is placed in an excess of horizontal abduction. The shoulder is potentially placed in an excess of horizontal abduction during three of the errors that will be quantified in this study. These errors include forearm supination as hand comes out of glove, open shoulder, and decreased trunk to elbow angle at SFC.

Despite the low rate of incidence, it is still important to be aware of signs and symptoms. This injury presents with a deep shoulder pain during maximal cocking, sporadic popping or catching during humeral external and internal rotation, and a loss of external rotators strength accompanied by atrophy in the infraspinous fossa.[2] Athletes tend to complain of pain during the late cocking phase and not being able to throw the ball as fast as they could previously.[21] Labral tears can also cause glenohumeral instability, which is also uncommon in adolescent pitchers.

Adolescents with labral tears should try conservative treatment before resorting to surgical repair.[10] If conservative treatment is not successful, arthroscopic surgical stabilization with suture anchors is normally required. Post operation rehabilitation includes shoulder immobilization with wrist, hand, and elbow exercises for the first four weeks.[15] Shoulder range of motion and gentle strengthening exercises begin after the first four weeks. A gradual, supervised throwing program can begin four month after surgery.[15] Return to play criteria is dependent on the athlete achieving full preinjury range of motion and strength and being able to participate pain free.[10] The athlete may not return to full competition for six to twelve months post operation.[15]

Rotator Cuff Tendonpathy

Rotator cuff injuries tend to be classified as overuse injuries related to secondary impingement, and although they are rare in the adolescent population, they are more likely to occur acutely.[30] Undersurface rotator cuff tears are caused by tensile overloads that can over during the event of release and phases of deceleration and follow through.[14,28,31] During the tensile overloads, eccentric stress is placed on the supraspinatus, external rotators and scapula stabilizers causing fatigue and higher risk of injury. Those cases of impingement that include rotator cuff involvement can also be affected by the four errors described in the *shoulder impingement* section. Treatment protocol involves rest until the athlete is asymptomatic and then begins to strengthen the rotator cuff muscles and scapular stabilizers, re-establish proper mechanics of shoulder and spine and restore range of motion.[10] After the athlete is pain free and has achieved full strength, a throwing program specifying proper throwing mechanics can take between one to three months to complete. The athlete is allowed to return to play after completing the program without return of symptoms.[10]

Proximal Humeral Epiphysioloysis

"Little League shoulder" is an overload injury to the proximal humeral epiphysis due to repetitive rotational stress. [2,15] The stresses that cause this injury in adolescent athletes are opposing forces of excessive external rotation of the distal humerus and increased internal rotation torque of the proximal humerus. [2,28,32] These kind of forces can be seen as a result of mechanics that begin with forearm supination as hand comes out of the subject's glove. Since cartilage is stronger during tension, the epiphysis is more at risk from torque.[32] When damage occurs, the most superficial portion of the epiphyseal is injured at the peak humeral torque.[32]

Athletes, who are at peak growth velocity, will complain of anterior and/or lateral shoulder pain with activity if affected by this pathology.[2] Their pain will progressively worsen with throwing and the point of maximal tenderness will be over the proximal humerus.[10] "Little league shoulder" can occur due to factors such as improper mechanics between the early cocking and deceleration phases. Contralateral trunk lean at maximum shoulder external rotation is another error that can lead to an increase of proximal forces on the shoulder. Adolescents with this injury should rest from pitching until symptoms resolve, be educated on proper pitching mechanics, and start a strengthening program for rotator cuff, periscapular muscles, and core musculature as well as working on the flexibility of their capsule.[15] The athlete normally misses at least three months with six weeks from diagnosis completely resting and the next six weeks not pitching, but completing the strengthening program previously mentioned.[28] A gradual, supervised pitching program must also be completed prior to the adolescent athlete returning to competition.

Medial Epicondylear Apophysistis and Medial Epicondylitis

"Little Leaguer's elbow" can range from irritation of the origin of the flexor pronator mass to an avulsion of the medial epicondyle.[2,11] This injury occurs from a combination of medial force and valgus stress.[16] Four of the errors that will be quantified in this study can lead to increased valgus stresses on the elbow. These errors include forearm supination as the hand comes out of the glove, backward lean at SFC, open shoulder position, and contralateral trunk lean at maximal shoulder external rotation. These are the same stresses that cause ulnar collateral ligament pathology in more skeletally mature athletes, but the epiphyseal plate is weaker than the surrounding ligaments in adolescent athletes.[2,32] Symptoms for these pathologies include the medial epicondyle being tender to palpate and may also be swollen.[2] The pitcher may also have a decrease of velocity and grip strength. An increase of volume or intensity in activity precedes the medial elbow discomfort.[2]

Conservative treatment has positive results for "Little Leaguer's elbow". A mandatory rest period from tensile forces for two to eight weeks is recommended.[33,34] Rehabilitation exercises that focus on achieving full elbow range of motion and strength can begin once athlete is pain free. After three to six months of treatment and the athlete has obtained pain free motion and full strength, a supervised throwing program can begin.[33,34] The time loss can vary depending on what the exact cause of pain is. For example if the pain is due to medial epicondyle apophysitis, the conservative treatment plan would involve no throwing for four to six weeks and then begin working on correcting the athlete's biomechanics once they are symptom free.[35]

Ulnar Collateral Ligament Pathology

Similar to "Little Leaguer's elbow", ulnar collateral ligament (UCL) pathology is due to tensile stresses placed upon the medial aspect of the elbow during valgus extension overload.[36] The anterior band of UCL resists valgus stresses as arm continues through external rotation during stride foot contact.[16] UCL injuries occur less often because the growth plates tend to fail before ligaments in adolescent athletes.[36,37] The same four errors that increase valgus stresses at the elbow and can potentially cause "Little Leaguer's elbow" can also be responsible for UCL injuries. Symptoms to be aware of may include complaints of medial elbow pain becoming worse during late cocking and early acceleration phases.[36] If an adolescent sustains this injury, the athlete is normally able to recall a particular event and was not able to continue to throw after the event. Conservative treatment is the preferred method to treat adolescents with UCL pathology. The conservative treatment may include splinting, reducing the inflammation, strengthening the flexor-pronator musculature, and re-gaining full pain free range of motion. Surgery will be considered if six months of conservation care does not resolve the symptoms. The same surgery that is done on an adult is completed on an adolescent and return to competition can take between six months to one year.

Panner's Disease and Osteochondritis Dissecans

Both of these pathologies can be described with stiffness and pain at an adolescent athlete's elbow. Panner's disease presents in athletes 10 years old and younger without history of trauma while osteochondritis dissecans (OCD) is more common in athletes 13+ years old.[2] The lateral elbow pain in both of these pathologies is related to compressive forces at the radiocapitellar joint that occurs during valgus extension overload.[2] Sixty percent of compressive forces is transferred across the radiohumeral joint just after ball release in combination of elbow extension during the deceleration phase.[16] Some authors propose that Panner's disease is due to these forces being transferred across the joint during a vulnerable point of skeletal growth.[36] The same four errors previously mentioned to cause an increase of valgus stresses at the elbow could also be involved with the causes of these pathologies.

Athletes with OCD will have symptoms of pain, swelling, locking, and inability to achieve full extension.[36] If the athlete does not have a loose or detached piece of bone, treatment can consist of up to six months of rest and modification of activity to reduce stress.[36] When a loose piece is present, the recommendation will be to have it removed with surgery. Depending on the age of the athlete and the severity of OCD, the athlete may not return to the same level of competition.[36] Most patients with Panner's disease are treated conservatively with a long period of rest and typically, normal capitellar growth will resume after the initial fragmentation stage.[36]

Current Assessment Tools

To prevent increased stresses on the joints that can eventually lead to injury, coaches need a tool to assess their athletes' pitching mechanics with the aim of identifying the errors that are associated with increased injurious forces or torques. Currently, the only pitching assessment tool that is available in the literature is the one developed by the American Sports Medicine Institute, based on their large database of pitching trials. There are also two studies that have quantified the stresses caused by biomechanical errors.[5,8] Each of these studies has explored similar biomechanical errors during the pitch. The purpose of this study is to establish the intra- and inter-rater reliability of biomechanical errors previously quantified.

The goal of this research done by the American Sports Medicine Institute was to develop a method to analyze pitching performance with standard video equipment.[9] The researchers identified twenty-four kinematic variables as important to pitching performance. These twenty-four variables needed for correct mechanics occur throughout all six phases of pitching are described in **Table 2**.

The twenty baseball pitchers that were included in this study ranged from the ages of 11 to 14 years old and had at least two seasons of pitching experience in organized baseball. The athletes were videotaped from a youth-sized pitching mound during spring training with 60 Hz camcorders.[9] The researchers also positioned a radar gun near one of the camcorders to quantify the velocity of each pitch. The athletes were instructed to throw four fastballs with maximal effort and were allowed thirty seconds rest between each pitch.[9] The three fastest strikes were selected for analysis. Their technique was evaluated by using a qualitative analysis protocol (QAP) that included a check list for the twenty-four variables.[9] Two independent raters, one of which was a coach and the other a trained biomechanist, completed the analysis. The raters were able to check either proper technique, high, or low.[9] For example, a pitcher was rated high if the his stride length was too long.[9]

The quantitative analysis was completed by placing plastic reflective markers on each of the major joints of the athlete. The reflective markers were tracked using a six-camera 240 Hz motion analysis system.[9] The three fastest strikes of the ten the athlete threw were analyzed. Since the windup and follow-through have low kinematic activity, only variables from stride to deceleration were analyzed.[9] The variables between these phases were the only variables compared between the motion analysis system and QAP because the motion analysis system was programmed to only digitize from stride foot contact on the mound until thirty milliseconds after ball release.[9]

Four of the QAP variables, elbow flexion at foot contact from the stride phase, sequence of hip-shoulder rotation from the arm cocking phase, and trunk flexion at ball release and horizontal adduction at ball release, were able to significantly reproduce the results of the high speed analysis high, low, or proper technique.[9] Inter-rater reliability showed 33% agreement on eight individual variables. The researchers established that they couldn’t complete an accurate profile of pitching mechanics with the current QAP. They also stated that there were obvious limitations with the use of their chosen equipment. In future studies, it has been suggested to modify the quality of pitching assessment design, higher camera frame rates and operator training.[9] Modifying the quality of pitching assessment design would allow other personal involved with baseball to utilize the tool. Using higher camera frame rates would allow a rater to pinpoint a more specific frame where an error may occur and improving the operator training would decrease potential errors in the results.

Table 2. Correct Pitching Kinematic Variables[9]

Phase	Variable
Foot contact	Preparatory movements Balance Hand separation Stride hip path
Stride	Stride length Stride offset Foot angle Knee flexion Horizontal adduction Abduction External rotation Elbow flexion
Arm cocking	Hip/shoulder rotation Trunk arching Use of glove arm Maximum elbow flexion Maximum external rotation
Ball Release	Trunk flexion Lateral trunk tilt Knee flexion Horizontal adduction Abduction Elbow flexion
Follow-through	Trunk flexion

Davis *et al* [5] established five correct mechanics to observe rather than errors during the phases of pitching. The first parameter, leading with the hips, involved the pelvis leading the trunk toward home plate during the early cocking phase. If the pitcher remained vertical during the phase, he was observed not to be leading with his hips and to have improper mechanics. The second parameter, hand-on-top position, was defined as whether the throwing hand was on top of the ball, indicating the arm was in pronation, as it came out of the glove.[5] If the forearm was in supination as it came out of the glove during cocking phase, this parameter was classified as incorrect. The third parameter, arm in throwing positions, was described as whether or not the athlete's elbow reached its maximum glenohumeral abduction by stride foot contact.[5] It is important for the athlete to be able to achieve humeral elevation before trunk rotation occurs. If the athlete's elbow does not reach maximum humeral elevation, this improper mechanic could lead to hyperangulation.[5] The fourth parameter, closed-shoulder position at stride foot contact or "opening up too soon" as pitching coaches define it, can also cause hyperangulation.[5] The last parameter, stride foot toward home plate, also occurs during stride foot contact and if performed incorrectly signifies an inefficient transfer of energy and improper timing of the trunk.[5]

The study was completed utilizing 169 uninjured youth baseball pitchers that were separated into two age ranges: 9-13 years old and 14-18 years old.[5] The data was analyzed using a quantitative motion analysis system and high-speed video. Fastballs were the only type of pitch thrown and each pitcher threw five pitches. The five parameters were compared with age, humeral internal rotation torque (HIRT), elbow valgus load (EVL), and pitching efficiency.[5] The limitations of this study included not evaluating multiple pitches from multiple angles, and the researchers needed to address the accuracy of video analysis. It is important to evaluate multiple pitches because it is a better representation of the pitcher's mechanics. Evaluating from multiple angles allows the raters more views to identify potential errors. Some errors may not be seen in the frontal view and therefore, a sagittal view is needed in order to properly identify the error. Determining the reliability of the rater's analysis is necessary in order to ensure errors are identified correctly both over time as well as between different raters. If an assessment tool is not reliable, changes in error scores over time may be due to decreased reliability instead of true alterations in pitching mechanics. In addition, if more than one rater cannot determine the same error score the tool cannot be translated into a clinical or sport setting where non-experts such as coaches can determine faulty mechanics in their athletes. The study suggested that future studies may want to evaluate the effect of improving core strength and pelvic stabilization on these parameters. If balance is not maintained with help from the global and local core stabilizer, lower extremity neuromuscular control is decreased and can lead to further faulty mechanics in the later phases of the pitch.

The two more easily observed parameters, hand-on-top position and closed-shoulder position, are also commonly discussed among pitching coaches. The hand-on top position causes early shoulder abduction while delaying humeral external rotation.[5] This occurs because when the forearm is pronated, the humerus remains internally rotated. If this parameter is completed incorrectly, stresses from improper mechanics can cause the arm to be late in the pitch causing hyperangulation of the shoulder. This unnecessary stress was found to be a contributor to shoulder injury.[5] As mentioned previously, performing the closed-shoulder position incorrectly also causes hyperangulation.

The youth pitchers between 9 and 13 years old were observed performing three or more parameters correctly and demonstrated a decrease in HIRT, EVL, and an increase of pitching efficiency.[5] The first parameter, leading with hips, was associated with increased HIRT, EVL, and decreased pitching efficiency. The last parameter, stride foot toward home plate, was not found to be a predictor for HIRT, EVL, or pitching efficiency. Davis *et al* [5] suggested that if pitchers performed both hand-on-top position and closed-shoulder position then they can improve their mechanics and possibly decrease HIRT and EVL. These two parameters will therefore be quantified in this future study.[3]

The study done by Oyama *et al* [8] is a modified version of the ASMI assessment tool. Similar to the study done by Davis *et al* [5], this study has 5 errors, or improper mechanics, analyzed during the phases of pitching.[8] The first error, open shoulder, is a common improper mechanic characterized by premature upper torso rotation that causes the anterior aspect of the leading shoulder to face the target at stride foot contact.[8] This error was also observed by Davis *et al*.[5] The second error, lateral trunk lean during stride foot contact, is characterized as lateral trunk lean towards the stance leg. This error results in the pitcher's head and upper torso not being aligned over the athlete's umbilicus vertically.[8] The third error, backward trunk lean during stride foot contact (BLSFC), results in the pitcher's head being behind the vertical line that passes through the athlete's ankle of his stride foot.[8] The forth error, lateral trunk lean at maximal external rotation (LLMER), is defined by the trunk leaning laterally towards the non-throwing shoulder. This error results in the pitcher's head not being more than a head width from the vertical line passing through the athlete's ankle of his stride foot.[8] The last error observed in this study, inadequate forward trunk flexion (FT), is defined by the mid-line of the trunk being tilted forward less than 20 degrees as the pitcher releases the ball.[8]

Pitchers between the ages of 13 and 19 years old with at least two seasons as a starter or reliever were included in this study. If the pitcher had an on-going injury that kept them from performing with normal mechanics they were excluded from the study. Pitchers were instructed to pitch 5 fastballs from a custom-built pitching mound in the laboratory. A force plate in the pitching mound slope captured ground reaction forces from stride foot contact. The ground reaction was captured at 900Hz and was determined at the instant of stride foot contact.[8] Three high-speed video cameras captured frontal and sagittal views while a radar gun captured ball speed. The three fastest pitches that were considered strikes were analyzed for this study.

One of the limitations of this study was not considering the movement of the scapula. It would be beneficial for future studies to take the movement of the scapula into account because it could explain faulty mechanics that occur at the shoulder. The pitchers also had to perform in an unfamiliar pitching environment. Assumptions were made by the researchers when calculating joint kinetics, and errors were captured on a higher speed camera than most on the market. However, there was high agreement between errors observed on high-speed camera versus standard camera. Meaning, use of a high speed camera increased the ability of a rater to grade the error the same each time. The final limitation of this study involved the researchers only assessing trunk mechanics.[8]

Two of the errors Oyama *et al* [8] found to be associated with increased joint loading were LLMER and inadequate or excessive FTT angle. These two errors were found necessary to be identified and modified to decrease the abnormal stress placed on the upper extremity. Pitchers with BLSFC demonstrated LLMER and pitchers with an excessively closed stance offset were four more times likely to have LLMER.[8] LLMER is also a strategy pitchers use for higher ball speed, therefore, making this error more difficult to correct.

Purpose

It is important to recognize errors in pitching mechanics and their contribution to upper extremity injury. An easy to use assessment tool would be beneficial for coaches to identify faulty pitching mechanics before injury to the shoulder or elbow occurs. To create such an assessment tool, research on more observable technical errors associated with increased joint loading must be done. Coaches, parents, and clinicians, who work with adolescent pitchers, can use the information in this study as an approach to injury prevention, decreasing the occurrence of shoulder and elbow injury throughout a pitcher's career by correcting biomechanical errors while the athletes are adolescences. Therefore, the purpose of this study is to establish the intra- and inter- rater reliability of previously quantified biomechanical errors in order to eventually create a reliable and valid assessment tool.

CHAPTER III: METHODOLOGY

Participants

Participants were recruited from local high schools, summer baseball leagues, and baseball academies in the Raleigh, Durham, and Chapel Hill area. Pitchers were males between the ages of 12 and 19 years old and must have participated as a starter or reliever for at least two seasons. Each participant and one legal guardian read and signed an informed consent form if the participant was under the age of 18, and completed an injury history survey prior to participation. Pitchers with any current injuries that prevented normal participation were excluded from the study. Sidearm pitchers were also excluded from this study.[8]

Instrumentation

Two high-speed video cameras (Model: Exilim FX-1, Casio Computer Co., Ltd., Tokyo, Japan) were used to film the pitching mechanics. The camera taking the frontal views was placed 3 meters in front of the anterior edge of the pitching mound at a height of 20 centimeters from the ground. [8] The camera capturing the sagittal plane mechanics was placed 3 meters lateral of the same side of the participant's throwing arm, perpendicular to the direction of the pitch at a distance of 75 centimeters in front of the pitching rubber at approximately the height of the pitcher's hip.[8] Videos from all cameras were captured at 300 frames per second. A radar gun (Sports Radar Ltd., Homosassa, FL, Model: SR3600) was held 3 meters behind the participant and in a way that the gun was aligned with the path of the ball after it is released to capture the speed of the ball.[8]

The Injury History survey included questions involving the participants' baseball participation experience, involvement in other athletic teams, pitching experience, and elbow and shoulder injuries and pain as seen in *Appendix 1*. The baseball participation experience, pitching experience, and injury and pain questions were reviewed by the investigator and were used to determine if the participant met the specified inclusion criteria. The section which assessed elbow and shoulder injury and pain began with a *yes* or *no* question to determine if the participant had ever sustained a throwing related injury to that particular body part that affected the athlete's participation for at least one week. If the subject marked *yes*, a series of possible injuries were listed for the participant to check. If an injury had been sustained, the participant was to fill in the date the injury first occurred, *yes* or *no* if they saw a doctor, and *yes* or *no* if they had surgery for the injury.

Procedures

Informed consent forms were approved by the University of North Carolina at Chapel Hill Institutional Review Board, and were signed and obtained from all participants prior to participating in the study. Consent from the participant's parent or guardian was also obtained prior to study for those participants between the ages of 12 and 17. Following consent, the participants completed the injury history survey.

Testing Preparation

The study took place at either an outdoor bullpen or indoor pitching facility in the Raleigh and Chapel Hill areas. The participants were instructed to warm up as they normally would prior to participating in a practice or game.

Collection of the Pitching Mechanics

After the participants completed their warm up, they were instructed to pitch as fast and as accurately as possible, aiming for the strike zone on the backstop. [8] Each participant pitched a minimum of 10 fastballs that included a minimum of 3 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds was given between each pitch. If the pitcher was unable to throw a minimum of 3 qualified strikes within 15 pitches, the pitcher took at least a 30-minute break and returned to the study. The frontal and sagittal videos and ball speed were captured for each pitch.[8]

Inter and Intra-rater Reliability

Three independent raters reviewed videos of each participant's three fastest strikes. Rater 1 , (EQ), the primary investigator, was a certified athletic trainer with three years of experience, Rater 2 (MD) was a former Division I pitcher, who medically retired due to an UCL injury, and Rater 3 (BP) was a certified athletic trainer with two years of experience, who pitched in an amateur league. To establish intra-rater reliability, the primary investigator reviewed each subject's videos three times with 5 days in between each review. To establish inter-rater reliability, the 3 raters (EQ, MD, BP) individually reviewed each subject's videos once. The primary investigator's initial review of each participant was compared to the other two raters' reviews to prevent repeat bias from occurring.

Following the same procedures as Oyama *et al* [8], the raters first identified the frames which corresponded with the instant of stride foot contact as well as maximal shoulder external rotation in either or both sagittal and/or frontal views. The frame for stride foot contact was identified as when the stride foot contacts the ground and stops as the lower leg continues to move. The frame for maximal shoulder external rotation was identified when the shoulder appears to be most externally rotated. Once the frames were identified, the raters were able to determine if the participant demonstrated any of the six errors to be quantified based off the descriptions of the errors in **Table 3**. Four of the six errors were graded with a *yes* or *no*. Stride foot position was graded with either *no error, open stride foot*, or *closed stride foot* and Trunk to Elbow Angle at Stride Foot Contact was graded with either *no error, less than 90* ^{o}, or *greater than 95* ^{o}(see **Appendix 2**). A pitcher was considered to have demonstrated the error if it was present in 2/3 pitches. These results were then used to test reliability between the three raters and the primary investigator's three reviews.

Table 3. Description of biomechanical errors

Frame	Error	Description
	Forearm Supination at full elbow extension	The hand is under or on the side of the ball when the elbow is fully extended
Stride Foot Contact	Open/Closed Foot Position	Open: Stride foot is lateral to back foot at SFC Closed: Stride foot is medial to back foot at SFC
	Backward Lean	The pitcher's head is lateral to the vertical line passing through the front of the ankle when the stride foot makes contact with the ground
	Open Shoulder	Premature upper torso rotation, where the sternum is visible
	Trunk to Elbow Angle	Less: Pitcher has less than 90^{0} of humeral elevation More: Pitcher has over 95^{0} of humeral elevation
Maximal Shoulder External Rotation	Contralateral Trunk Lean	The pitcher's head is lateral to the vertical line passing through the stride foot

Data Analysis

Separate Cohen's kappa coefficients were used to establish intra- and inter-rater reliability of individual pitching errors. Scores were interpreted based off **Table 4**.

Table 4. Kappa Interpretations Criteria[38]

Kappa	Interpretation
< 0	Poor agreement
0.00 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

CHAPTER IV: MANUSCRIPT

Background: It is important to recognize errors in pitching mechanics and their contribution to upper extremity injury. An easy to use assessment tool would be beneficial for coaches to identify faulty pitching mechanics before injury to the shoulder or elbow occurs. To create an assessment tool capable of identifying faulty pitching mechanics, more observable technical errors associated with increased joint loading must first be identified and then, their reliability must be established. The purpose of this study is to establish the intra- and inter-rater reliability of previously studied biomechanical errors so that they can eventually be implemented as a tool in a clinical setting.

Hypothesis: The error scoring system will have acceptable intra- and inter-rater reliability.

Study Design: A descriptive field study.

Methods: 34 male pitchers between the ages of 12 and 17 years old (age: 14.0±1.4 years old, height: 169.3±12.4cm, mass: 62.2±12.8kg), who participated as a starter or reliever for at least two seasons were enrolled. Following an adequate self-selected warm-up, each participant pitched a minimum of 10 fastballs that include a minimum of 3 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds was given between each pitch. High-speed video cameras were used to capture both frontal and sagittal plane pitching mechanics, and ball speed was captured for each pitch.[8] Both the frontal and sagittal videos were analyzed independently by three raters for the intra- and inter-rater reliability of 6 biomechanical errors. Cohen's kappa coefficients were ran to establish intra- and inter-rater reliability.

Results: Forearm supination at stride foot contact had substantial to almost perfect intra-rater reliability and poor to slight inter-rater reliability. Stride foot position at stride foot contact had moderate to substantial intra-rater reliability and moderate to almost perfect inter-rater reliability. Backward lean at stride foot contact had moderate to almost perfect intra-rater reliability and slight to moderate inter-rater reliability. Open shoulder at stride foot contact had fair to moderate intra-rater reliability and slight to moderate inter-rater reliability. Trunk to elbow angle at stride foot contact had moderate to substantial intra-rater reliability and fair to moderate inter-rater reliability. Contralateral trunk lean at maximal external rotation had moderate to substantial intra-rater reliability and moderate inter-rater reliability.

Conclusions: All 6 errors had acceptable ($K \geq 0.50$) intra-rater reliability and 3 out of 6 biomechanical errors (stride foot position at stride foot contact, backward lean at stride foot contact, and contralateral lean at max external rotation) had acceptable ($K \geq 0.50$) inter-rater reliability.

Clinical Relevance: Establishing the reliability of previously studied biomechanical errors is a critical step towards creating a valid and reliable assessment tool to allow coaches, parents, athletic trainers, and other sports medicine professionals to identify faulty pitching mechanics, which predispose these athletes to serious upper extremity injuries.

INTRODUCTION

Currently in the United States there are 11.5 million baseball players, with the majority of these players younger than age 18.[1] While participation in athletics has its health benefits, it also has its health risks such as musculoskeletal injury. More than half of the musculoskeletal injuries seen in adolescent baseball athletes involve the upper extremity.[2] Of the 58% of upper extremity injuries that occur during baseball, 73% of shoulder injuries and 70% of elbow injuries occur during pitching.[3] Half of all pitchers experience upper extremity pain that prevents participation at some point in their career.[4]

It has been previously stated that faulty pitching mechanics are associated with injury.[5,7,8,9] Faulty pitching mechanics lead to repetitive, greater magnitude stress on the joints which may leave the soft tissue around the shoulder and elbow susceptible to damaging microtrauma[5] Pitching errors are noted throughout the pitching motion. [7,8] However, the errors that occur during arm-cocking and arm-acceleration phases are considered particularly dangerous, because the loads placed on the shoulder and elbow joints are the highest during these phases. [7,8] Moreover, the errors that occur before or at the stride foot contact that may lead to the errors during the arm-cocking and acceleration phases may be potentially harmful to the joints.[7,8]

In order to prevent injurious stresses placed on the upper extremity during pitching, there is a need for a tool that allows coaches and clinicians to identify pitchers with high risk of injury. Currently, the only pitching assessment tool that is available in the literature is the one developed by the American Sports Medicine Institute, based on their large database of pitching trials. However, the assessment tool that consists of 24-point checklist of technical parameters that can be observed during the entire pitching motion has major limitations. [9] First, while most of the 24 technical parameters could be identified with relatively high reliability, the visual evaluation of the parameters had poor agreement with the quantitative data collected using the motion capture system. [9] Second, since the tool was not intended to identify pitchers with higher risk of injury, the evaluation of pitching technique using this scale does not predict loads placed on the joint, pitchers' risk of injury, or performance. [9]

More recently, in an attempt to identify visually identifiable pitching technical errors that may be predictive of injury risk, Davis *et al*[5] studied whether five technical parameters that they identified are associated with increased joint loading. Davis *et al*[5] found that if a pitcher between 9-13 years old demonstrated forearm supination as the hand comes out of the glove, open shoulder at stride foot contact, and one other parameter correctly then the pitcher would have decreased humeral internal rotation torque, decreased elbow valgus load, and increased pitching efficiency. A study by Oyama *et al*[8] also examined whether the technical parameters pertaining to pitcher's trunk movement are linked to increased joint loading, and demonstrated that excessive contralateral trunk lean at maximal humeral external rotation was linked to increased joint loading. This study also found that backward lean at stride foot contact and stride foot position at stride foot contact increased the likelihood that the pitcher would also demonstrate contralateral trunk lean.[8] The limitation of these studies, however, is that they did not report how reliably clinicians and coaches can identify these parameters.[5,8] Therefore, the purpose of this study was to establish the intra- and inter-rater reliability of previously studied biomechanical errors that have been proven to cause injurious forces at the elbow and shoulder. In order to develop a true clinical screening tool that could be predictive of injury risk in the future, it needs to be both valid and reliable.

METHODS

Participants

Participants were recruited from local high schools, summer baseball leagues, and baseball academies around the Raleigh, Durham, and Chapel Hill area. Thirty-four male pitchers between the ages of 12 and 17 years old participated in the study. For a pitcher to be enrolled in the study he must have participated as a starter or reliever for at least two seasons. Pitchers with any current injuries that prevent normal participation were excluded from the study. Sidearm pitchers were also excluded from this study.[8]

Instrumentation

Two high-speed video cameras (Model: Exilim FX-1, Casio Computer Co., Ltd., Tokyo, Japan) were used to film the pitching mechanics. The camera capturing frontal plane mechanics was placed 3 meters in front of the anterior edge of the pitching mound at a height of 20 centimeters from the ground. [8] The camera capturing the sagittal plane mechanics was placed 3 meters lateral of the same side of the participant's throwing arm, perpendicular to the direction of the pitch at a distance of 75 centimeters in front of the pitching rubber at approximately the height of the pitcher's hip.[8] Video from both cameras was captured at 300 frames per second. A radar gun (Sports Radar Ltd., Homosassa, FL, Model: SR3600) was held 3 meters behind the participant and in a way that the gun was aligned with the path of the ball after it is released to capture the speed of the ball.[8]

Procedures

Data collection occurred at either an outdoor bullpen or indoor pitching facility. Informed consent forms were approved by the university's Institutional Review Board and were signed and obtained along with the injury survey were from all participants prior to participating in the study. Consent from the participant's parent or guardian were also obtained prior to study for those participants between the ages of 12 and 17.

Collection of the Pitching Mechanics

After the participants completed their own desired warm up, they were instructed to pitch as fast and as accurately as possible, aiming for the strike zone on the backstop.[8] Each participant pitched a minimum of 10 fastballs that included a minimum of 3 strikes, defined as pitches that hit the strike zone on the backstop. A rest of 30-60 seconds was given between each pitch. Each pitch was recorded from the frontal and sagittal view, and ball speed was recorded for each pitch.[8] The three fastest strikes were used for analysis.

Inter and Intra-rater Reliability

Three independent raters reviewed videos of each participant's three fastest strikes. Rater 1 , (EQ), the primary investigator, was a certified athletic trainer with three years of experience, Rater 2 (MD) was a former Division I pitcher, who medically retired due to an UCL injury, and Rater 3 (BP) was a certified athletic trainer with two years of experience, who pitched in an amateur league. To establish intra-rater reliability, the primary investigator reviewed each subject's videos three times with 5 days in between each review. To establish inter-rater reliability, the 3 raters (EQ, MD, BP) individually reviewed each subject's videos once. The primary investigator's initial review of each participant was compared to the other two raters' reviews to prevent repeat bias from occurring.

Following the same procedures as Oyama *et al* [8], the raters first identified the frames in which the instant of stride foot contact and maximal shoulder external rotation occurred in both sagittal and frontal views. The frame for stride foot contact was identified as when the stride foot contacts the ground and stops as the lower leg continues to move. The frame for maximal shoulder external rotation was visually identified at the peak of shoulder external rotation. Once the frames were identified, the raters determined if the participant had demonstrated the six errors based off the descriptions of the errors in **Figures 1-6**. Four of the six errors were graded with a *yes* or *no*. Stride foot position was graded with either *no error*, *open stride foot*, or *closed stride foot* and Trunk to Elbow Angle at Stride Foot Contact was graded with either *no error, less than* 90^{o}, or *greater than* 95^{o} (see **Appendix 2**). A pitcher was considered to have demonstrated the error if it was present in 2/3 pitches. These results were then used to test reliability between the three raters and the primary investigator's three reviews.

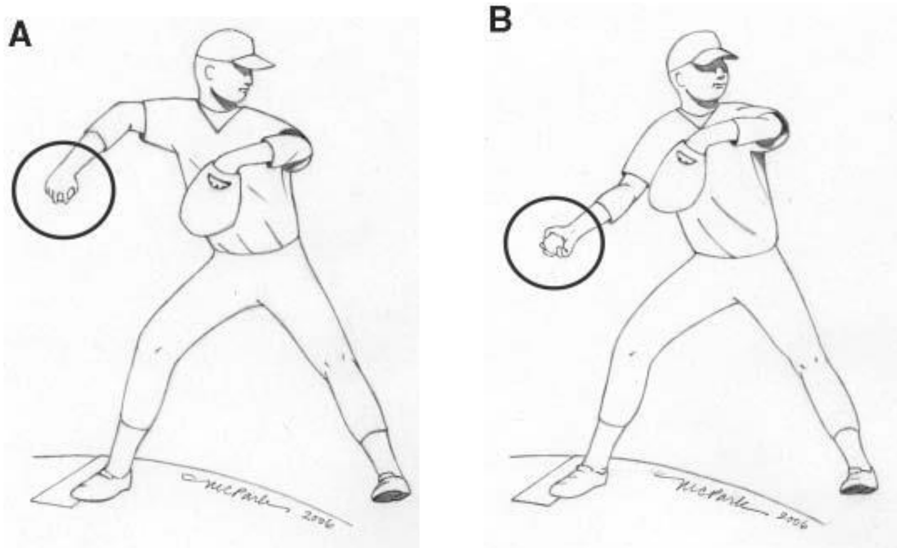

Figure 1**.** A, forearm pronation (correct mechanics[5]) B, forearm supination at full elbow extension (incorrect mechanics[5]) defined as the hand is under or on the side of the ball when the elbow is fully extended. This error as described by Davis *et al*[5] as *hand-on-top as the ball left the glove* can cause increased stresses placed on the structures of the medial elbow.

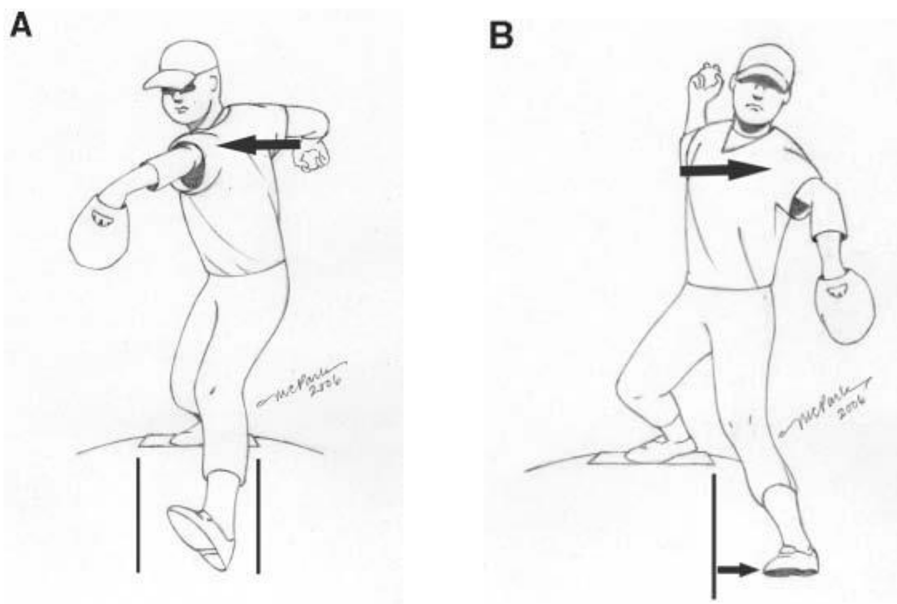

Figure 2. A, the stride foot should be directly facing home plate (correct mechanics[5]) B, open stride foot position at stride foot contact (incorrect mechanics[5]) defined as when the stride foot is lateral to the back foot by at least one foot length. It is also considered to be an error when the stride foot is medial to the back foot (closed stride foot position). The error has been thought to indicate inefficient transfer of energy as well as cause improper trunk rotation timing.[5] Oyama *et al*[8] also found this error to predispose the pitcher to also demonstrate *contralateral trunk lean at maximal external rotation*.

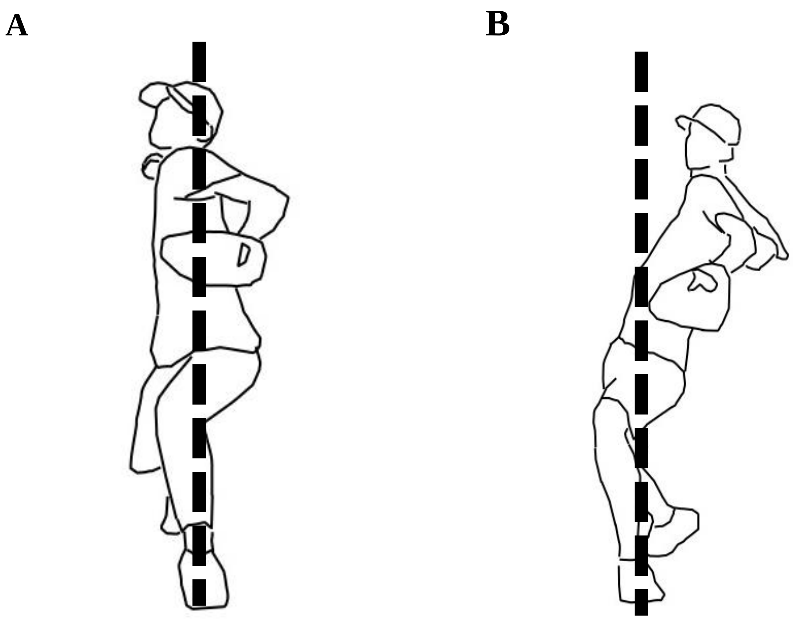

Figure 3. A, the head, torso, and ankle of the stride foot should all be aligned during stride foot contact (correct mechanics[8]) B, backward lean at stride foot contact (incorrect mechanics[8]) is defined as when the head deviates from the vertical line passing through the front of the ankle when the stride foot makes contact with the ground. This error has been previously shown to lead to contralateral lean at maximal external rotation.[8]

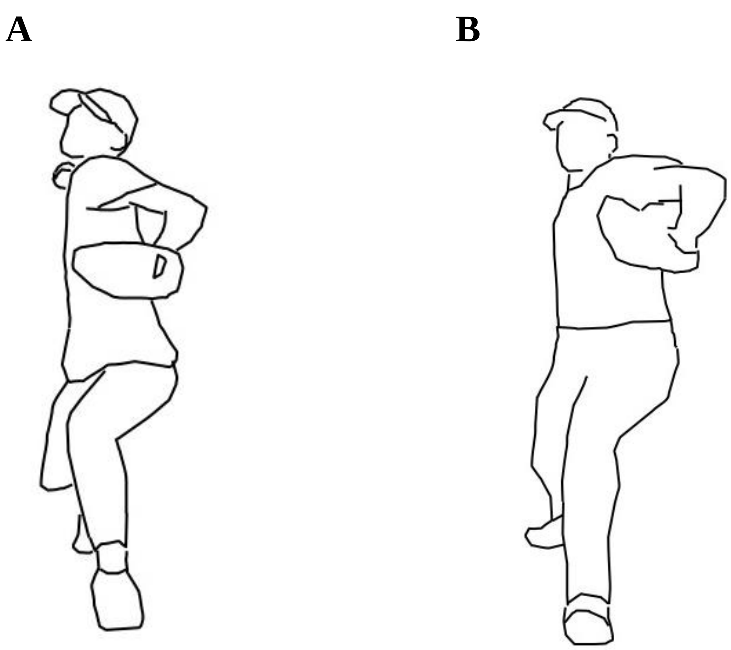

Figure 4. A, the lateral aspect of the shoulder should be aligned directly with the target (correct mechanics[8]) B, open shoulder at stride foot contact (incorrect mechanics[8]) is defined differently than previously described by Oyama *et al*[8] as premature upper torso rotation, where the sternum is visible. When this premature rotation occurs in congruency with forearm supination as the hand comes out of the glove, increased stresses are placed on the structures of the medial elbow and anterior shoulder.

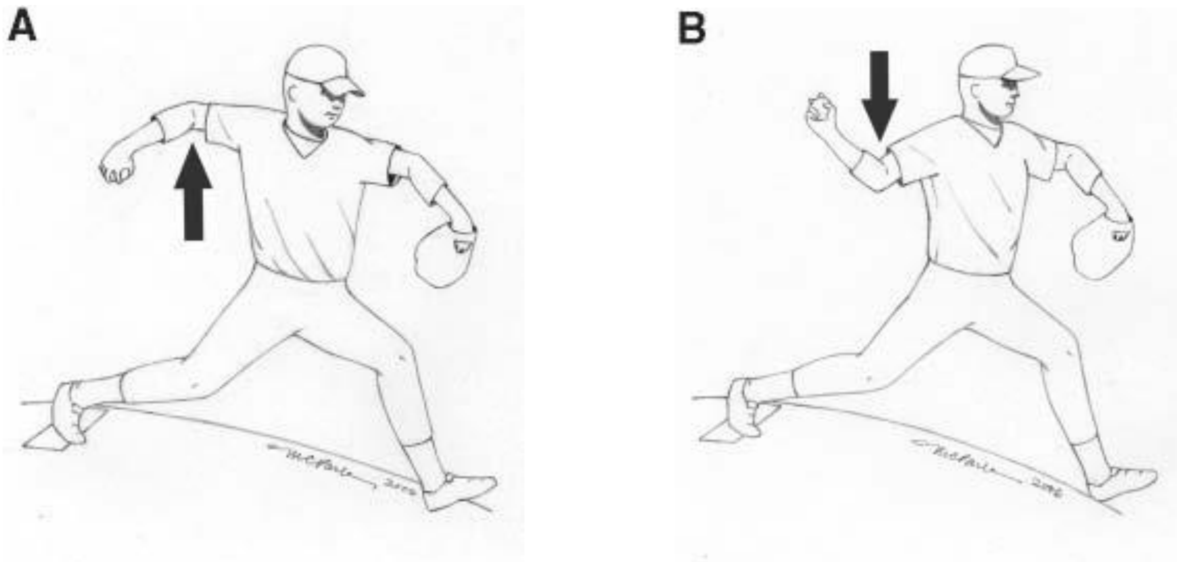

Figure 5. A, the elbow to trunk angle should be 90^0-95^0 at stride foot contact (correct mechanics[5]) B, decreased trunk to elbow angle (incorrect mechanics[5]) is defined as when the humerus does not reach an appropriate elevation prior to significant trunk rotation occurs. Appropriate elevation allows the scapula to achieve a stable position before trunk rotation and helps assist the transfer of energy to the upper extremity.[5]

A **B**

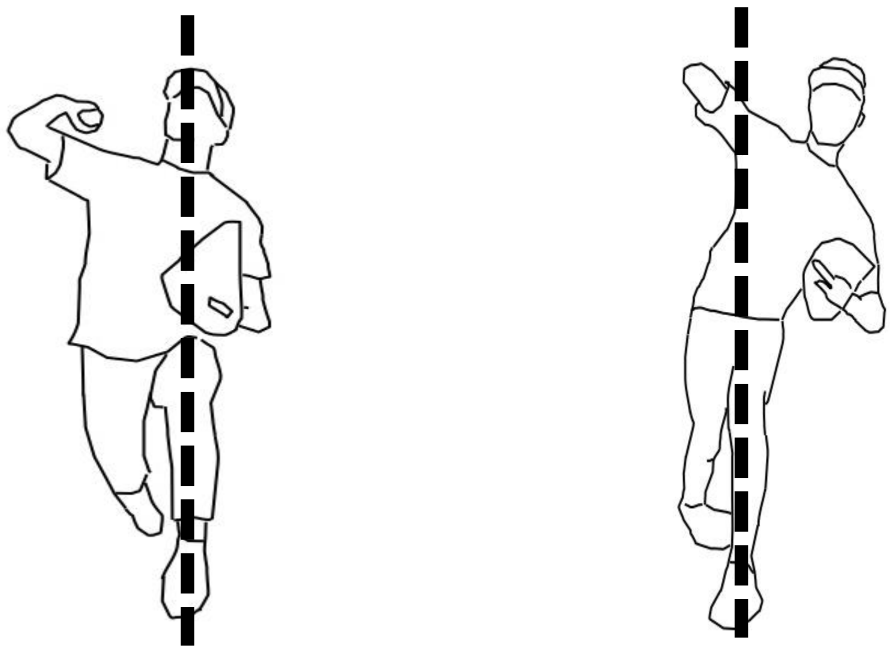

Figure 6. A, the head, torso, and ankle of the stride foot should all be aligned when the shoulder is in maximal external rotation (correct mechanics[8]) B, contralateral lean at maximal external rotation (incorrect mechanics[8]) is defined as when the head deviates from the vertical line passing through the front of the ankle when the stride foot makes contact with the ground. Pitchers that demonstrate this error experience increased peak elbow varus moment, increased peak shoulder internal rotation moment and increased peak proximal forces and shoulder and elbow joints. [8]

Data Analysis

Separate Cohen's kappa coefficients were used to establish intra- and inter-rater reliability of individual pitching errors. An a priori alpha level of 0.05 was set. Statistical analyses were run using SPSS version 21.0 (SPSS Inc., Chicago, IL). Agreement was interpreted based on the kappa interpretations criteria established by Landis *et al*[38]: poor agreement is established when the kappa value is less than 0, slight agreement is between 0.01 and 0.2, fair agreement is between 0.21 and 0.4, moderate agreement is between 0.41 and 0.6, substantial agreement is between 0.61-0.8, and almost perfect agreement is between 0.81-1.

RESULTS

The study included 34 pitchers who participated in video analyses. All participants were male that had participated in baseball for a minimum of 2 seasons. Demographics of the 34 participants are presented in **Table 5**. The frequency of each error found to be present in one of these participants by the raters is found in **Table 6**.

Table 5. Participant Demographics

	Mean ± SD	Range
Age (years)	14.0 ± 1.4	12.0 – 17.0
Mass (kg)	62.2 ± 12.8	38.6 – 88.2
Height (cm)	169.3 ± 12.4	139.7 – 190.5
Years of Participation (years)	7.3 ± 2.2	3.0 – 13.0
Years of Pitching (years)	4.9 ± 1.8	2.0 – 8.0
Average Velocity during Testing (MPH)	65.5 ± 8.4	47.0 – 86.0

Table 6. Error Frequency Based on all Three Raters Findings

	Frequency	Percentage of Participants with Error
Forearm Supination	4	12%
Stride Foot Position	10	29%
Backward Lean	4	12%
Open Shoulder	11	32%
Trunk to Elbow Angle	10	29%
Contralateral Trunk Lean	19	56%

Cohen's kappa coefficients were calculated for the intra-rater reliability of each individual error based on the three separate reviews by rater 1 (see **Table 7**). Forearm supination at stride foot contact had almost perfect agreement between the first and second review as well as the first and third review and had substantial agreement between the second and third review. Stride foot position at stride foot contact had moderate agreement between the first and third review and had substantial agreement between the first and second review and second and third review. Backward lean had almost perfect agreement between the first and second review, but had moderate agreement between the first and third review and the second and third review. Open shoulder at stride foot contact had moderate agreement between first and second review, slight agreement between the first and third review, and substantial agreement between the second and third review. Trunk to elbow angle at stride foot contact had substantial agreement between the first and second review and second and third and moderate agreement between the first and third review. The final error, contralateral trunk lean at maximal humeral external rotation had substantial agreement between the first and second review and first and third review and moderate agreement between the second and third trial.

Cohen's kappa coefficients were also calculated to determine if there was agreement between the three rater's reviews of the six biomechanical errors (see **Table 7**). This study incorporated three raters in order to compare the reliability between the primary investigator and a former collegiate pitcher, and also compare the reliability between the investigator and an Athletic Trainer, the clinician. Forearm supination at stride foot contact had poor agreement between the primary investigator and the former pitcher's review, but had slight agreement between the primary investigator's and the clinician's review. Stride foot position at stride foot contact had moderate agreement between the primary investigator and the former pitcher's review as well as the primary investigator and the clinician's review. Backward lean at stride foot contact had poor agreement between the primary investigator and the clinician's review, but had moderate agreement between the primary investigator and the former pitcher's review. Open shoulder had slight agreement between the primary investigator and the former pitcher's review, fair agreement between the primary investigator and the clinician's. Trunk to elbow angle at stride foot contact had fair agreement between the primary investigator and the clinician's review, but had moderate agreement between the primary investigator and the former pitcher's. Contralateral trunk lean at maximal external rotation had moderate agreement between all three raters.

Table 7. Intra- and Inter-Rater Reliability of 6 Biomechanical Errors

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)

DISCUSSION

The purpose of this study was to establish the intra- and inter-rater reliability of 6 biomechanical errors that have previously been studied to cause unnecessary forces at the joints of the upper extremity. Although improper biomechanics have been found as a predisposing factor for injury, there is currently no tool to help identify these errors. After running the kappa statistics, we established acceptable intra-rater reliability with all errors, and acceptable inter-rater reliability for stride foot position at stride foot contact, backward lean at stride foot contact, and contralateral lean at maximal external rotation.

Davis *et al* [5] had found that the forearm supination at stride foot contact and open shoulder were two of the more easily observed errors. Both errors were discussed thoroughly amongst the raters and it was difficult finalizing the definitions of these two errors, which could have led to unacceptable reliability. The forearm supination at stride foot contact and open shoulder errors were included in this study because Davis *et al* [5] found that if they were completed correctly it could decrease valgus load on the elbow and the humeral internal rotation torque. These two errors should be included and more clearly defined in future studies that look at developing a pitching assessment tool.

Forearm supination at full elbow extension was one of the errors that had been described differently than Davis *et al* [5] in this study in hopes of increasing reliability, but ended up being one of the errors that did not have acceptable inter-rater reliability between all 3 raters. The definition of forearm supination was changed from the point the hand leaves the glove to full elbow extension because it is not always easy for the raters to see the hand just after it leaves the glove. Another reason this definition was changed was that the hand position at full elbow extension determines the position of the shoulder when it reaches external rotation, which could increase injurious forces. Despite this change in definition, there was still disagreement between the three raters with whether the pitcher’s hand was correctly on top of the ball or incorrectly on the side or bottom. To improve this error’s inter-rater reliability in the future, the rater’s need to meet to agree on how the hand is on top, on the side, or on the bottom is defined.

Open shoulder at stride foot contact was also thoroughly discussed prior to data analysis due to the change in definition of stride foot contact. Originally, this error was described by Davis *et a l*[5] as when the anterior aspect of the shoulder faced home, but was then changed to when the sternum is visible. Open shoulder at stride foot contact did not have acceptable reliability between the primary investigator and the clinician (Κ = .336, p=0.021) and there was no significance in the agreement between primary investigator and the former pitcher (Κ = .070, p=0.628) for this error. A possible explanation for the lack of agreement between raters may be that the definition of the sternum being visible is vague and may mean something different to each rater. For example, the primary investigator may have thought that the sternum was only visible if it is faced directly at home plate while the former pitcher may have thought that the pitcher had this error if the sternum was directed between home and either first or third base. In future studies, this error needs to be more clearly defined by where the sternum is directed.

Trunk to elbow angle at stride foot contact had moderate agreement between the primary investigator and the former pitcher (Κ = .469, p=0.001), but only had fair agreement between the primary investigator and the clinican's review (Κ = .353, p=0.007). The proper humeral elevation was determined to be between 90^0-95^0. The exact humeral elevation that leads to proper torso rotation has been found to be 93±11°.[17] Due to the fact the primary investigator was aware of the variability associated with humeral elevation, it is possible that this rater was less strict with the 90^0-95^0 range. Another reason there could have been disagreement with this error amongst the raters was dependent on how the error was judged. The correct way to approach determining this error was to look at the angle made with the humerus and the torso. A rater could easily be thrown off by the athlete's clothing with this error.

Two of the errors that this study found to have both acceptable intra- and inter-rater reliability were backward lean at stride foot contact and contralateral lean at maximal external rotation. Oyama *et al* [8] found contralateral lean to be associated with increased joint loading at the elbow and shoulder. Additionally, pitchers who demonstrated backward lean at stride foot contact also demonstrated contralateral lean at maximal external rotation and pitchers with an excessively closed stance offset (stride foot position) were four more times likely to have contralateral lean.[8] Stride foot position at stride foot contact was the third error that was found to have both acceptable intra- and inter-rater reliability.

Finding stride foot position at stride foot contact, backward lean at stride foot contact and contralateral lean at maximal external rotation to have acceptable intra- and inter-rater reliability is clinically significant. These three errors can now be used as a base for an error scoring system to identify mechanics that cause unnecessary injurious forces. As stated previously, stride foot position and backward lean at stride foot contact have been found to predispose a pitcher to also demonstrate contralateral trunk lean at maximal eternal rotation.[8] Contralateral lean at maximal external rotation has been shown to increase stresses placed on the structures of the medial elbow and anterior aspect of the shoulder.[8] These forces could predispose an athlete to Little Leaguer's elbow, Panner's disease, OCD's, Little Leaguer's shoulder, secondary shoulder impingement, and rotator cuff pathology.

For this quality pitching assessment to be useful, acceptable inter-rater reliability for forearm supination at stride foot contact, open shoulder at stride foot contact, and elbow to trunk angle at stride foot contact must be established. This tool is limited due to only three out of the six errors having acceptable inter-rater reliability. The definitions of these three errors need to not only be thoroughly discussed, but also pilot testing of the new definitions should be done to assure that each rater understands the definition across the board as the same. It was evident through the acceptable intra-rater reliability that the primary investigator had her understanding of each definition, but due to unacceptable inter-rater reliability of those three errors, the primary investigator's definitions appeared to have differed from the former pitcher's and the clinician's. Due to the alternations of the definitions of open shoulder and stride foot contact and forearm supination at full elbow extension, the forces that have previously been quantified for these errors may not apply. If future researchers choose to keep the definitions used in this study, they would need to also quantify the stresses at the elbow and the shoulder. Our results also may be attributed to the subject size. Originally, data was collected on 50 subjects, but only 34 participants were included in the data analysis.

Future research should include establishing acceptable inter-rater reliability with sagittal view errors and potentially reviewing other easy to visually identify errors that the literature has found to cause injurious forces that were not included in this study. This study lays the foundation for the development of a clinically applicable assessment tool which has the potential of identifying faulty pitching mechanics to decrease the injury associate with pitching. Beyond continuing to determine the most critical pitching errors which may be associated with increased upper extremity joint loading, future research should aim to determine if there is a relationship between the reliable pitching errors and upper extremity injury history. This research should include athletes with more experience instead of youth and adolescent pitchers due to a greater chance of having previous injury history.

CONCLUSION

Acceptable intra-rater reliability was established for all six of the biomechanical errors that were included in this study. Acceptable inter-rater reliability was established for stride foot position at stride foot contact, backward lean at stride foot contact, and contralateral lean at max external rotation.

Appendix 1

Tell Us About Your Baseball Participation Experience and Arm Injuries

Please answer the following questions to the best of your knowledge

Part 1: Tell us about your Baseball Participation Experience

1. What position(s) do you expect to play for your Baseball team this season? (Check all that apply)

- ☐ Pitcher
- ☐ Catcher
- ☐ 1st base
- ☐ 2nd base
- ☐ 3rd base
- ☐ Short stop
- ☐ Outfield
- ☐ Unknown/Not sure

1a. Of the positions checked above, which is your PRIMARY position? (ONLY check one)

- ☐ Pitcher
- ☐ Catcher
- ☐ 1st base
- ☐ 2nd base
- ☐ 3rd base
- ☐ Short stop
- ☐ Outfield
- ☐ Unknown/Not sure

1b. Of the positions checked above, which is you SECONDARY position?(ONLY check one)

- ☐ Pitcher
- ☐ Catcher
- ☐ 1st base
- ☐ 2nd base
- ☐ 3rd base
- ☐ Short stop
- ☐ Outfield
- ☐ Unknown/Not sure

2. Including the Spring 2014 season, how many years have you played baseball, INCLUDING t-ball?

☐ <1 year	☐ 5 years	☐ 10 years	☐ 15 years
☐ 1 year	☐ 6 years	☐ 11 years	☐ 16 years
☐ 2 years	☐ 7 years	☐ 12 years	☐ 17 years
☐ 3 years	☐ 8 years	☐ 13 years	
☐ 4 years	☐ 9 years	☐ 14 years	

3. Including the Spring 2014 season, how many years have you played baseball, EXCLUDING t-ball?

☐ <1 year	☐ 5 years	☐ 10 years	☐ 15 years
☐ 1 year	☐ 6 years	☐ 11 years	☐ 16 years
☐ 2 years	☐ 7 years	☐ 12 years	☐ 17 years
☐ 3 years	☐ 8 years	☐ 13 years	
☐ 4 years	☐ 9 years	☐ 14 years	

4. Within the past year, please check all the seasons you played baseball on an organized team (ex. Club team, summer ball, fall ball, travel ball)?

2014 ☐ Spring ☐ Summer ☐ Fall ☐ Did not play baseball in 2014

5. Within the past years, please check all seasons you PLAYED baseball on multiple organized teams at the same time?

2014 ☐ Spring ☐ Summer ☐ Fall ☐ Did not play baseball in 2014

6. Within the past 3 years, please check all the seasons you PITCHED on multiple organized teams at the same time?

2014 ☐ Spring ☐ Summer ☐ Fall ☐ Did not pitch on multiple teams

7. Please check all the organized team/individual sports you participated in the past year. (This does not include sports you played in as a part of your class activities or in pickup games)

☐ None	☐ Tennis
☐ Football	☐ Swimming
☐ Basketball	☐ Cross Country
☐ Soccer	☐ Track
☐ Lacrosse	☐ Volleyball
☐ Wrestling	☐ Waterpolo
☐ Golf	☐ Others (Please specify): ☐☐☐☐☐☐☐☐☐☐☐☐

Part 2: Tell us about your Pitching Experience

If you have NEVER been a pitcher, please skip this page and continue with the next page.

1. Including the 2014 season, how many years have you pitched on an organized team?

- ☐ <1 year
- ☐ 1 year
- ☐ 2 years
- ☐ 3 years
- ☐ 4 years
- ☐ 5 years
- ☐ 6 years
- ☐ 7 years
- ☐ 8 years
- ☐ 9 years
- ☐ 10 years
- ☐ 11 years
- ☐ 12 years

2. Within the past year, please check all the seasons that you pitched in an organized team. If you pitched, please check the role you played as a pitcher during each season (ex. starter vs bull pen/relief pitcher).

Summer 2013 ☐ Did not Pitch ☐ Pitched → ☐ Starter ☐ Relief pitcher ☐ Both equally

Fall 2013 ☐ Did not Pitch ☐ Pitched → ☐ Starter ☐ Relief pitcher ☐ Both equally

Spring 2014 ☐ Did not Pitch ☐ Pitched → ☐ Starter ☐ Relief pitcher ☐ Both equally

3. Please check the types of pitch you throw in games

- ☐ Fastball
- ☐ Curveball
- ☐ Slider
- ☐ Knuckle ball
- ☐ Knuckle-curve ball
- ☐ Change-up
- ☐ Slurve
- ☐ Other (Please specify): ☐☐☐☐☐☐☐☐☐

Part 3: Elbow Injuries and Pain During Your Baseball Career

Have you ever had an ELBOW throwing-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career?

☐ No (if no, proceed to next page) ☐ Yes

If YES, please **check ALL** the injuries you had that were sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career, and answer the questions to the right.

Injury	When did you have the injury for the first time?	Did you see a doctor for this?	Did you get a surgery for this?
☐ Ulnar collateral ligament injury (Sprain, tear, rupture, irritation)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Tendonitis on the inside of the Elbow ("Medial epicondylitis")	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Other Tendonitis (i.e. Biceps, Triceps, lateral epicondylitis)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Stress fracture or bone chip	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Ulnar nerve injury	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Growth plate fracture	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Non-specific pain/ soreness From overuse	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Other: Please specify	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes

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☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Part 4: Shoulder Injuries and Pain During Your Baseball Career

Have you ever had a SHOULDER throwing-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career?

☐ No (If no, proceed to the next page) ☐ Yes

If YES, please **check ALL** the injuries you had that were sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your baseball career, and answer the questions to the right.

	When did you have the injury for the first time?		Did you see a doctor for this?		Did you get a surgery for this?	
☐ Rotator cuff (tendonitis, strain Irritation, tear, impingement)	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Labrum injury (tear, irritation SLAP lesion)	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Biceps tendon (tendonitis, Subluxation, irritation)	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Other muscle strain (not rotator or biceps)	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Bursitis	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Stress fracture or bone chip	☐☐ (Month)	☐☐☐☐ (Year	☐ No	☐ Yes	☐ No	☐ Yes
☐ Growth plate fracture	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Thoracic outlet syndrome	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Non-specific pain/ soreness From overuse	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes
☐ Other: Please specify	☐☐ (Month)	☐☐☐☐ (Year)	☐ No	☐ Yes	☐ No	☐ Yes

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☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Appendix 2

Pitching Error Scoring System

Subject # ____________________________ **Video Date____________________________**

Evaluator ____________________________ **Date of Evaluation ______________________**

Pitch #___________

Frontal Plane View	**No Error**	**Error**
1. Stride Foot Position @ SFC	☐ Stride Foot Toward Home	☐ Open Stride Foot ☐ Closed Stride Foot
2. Backward Lean @ SFC	☐ Head, Shoulders, Hips, Ankle in Line	☐ Head is lateral to perpendicular line through the ankle
3. Upper Torso Rotation @ SFC	☐ Lateral Shoulder Faces Home	☐ Sternum is visible
4. Contralateral Trunk Lean @ Max shoulder ER	☐ Head, Torso, Ankle in Line	☐ Head is lateral to perpendicular line through the ankle

Sagittal Plane View	**No Error**	**Error**
5. Forearm Supination @ full elbow extension	☐ Hand on top of ball (palm down)	☐ Hand on the side or below the ball
6. Trunk to Elbow Angle SFC	☐ 90^0-95^0 of Elevation	☐ less than 90^0 ☐ greater than 95^0

Evaluator's Notes: ____

____

Total # Errors:________________________

REFERENCES

1. Lawson BR, Comstock RD, Smith GA. Baseball-related injuries to children treated in hospital emergency departments in the United States, 1994-2006. *Pediatrics.* Jun 2009;123(6):e1028-1034.

2. Shanley E, Thigpen C. Throwing injuries in the adolescent athlete. *International journal of sports physical therapy.* Oct 2013;8(5):630-640.

3. Dick R, Sauers EL, Agel J, et al. Descriptive epidemiology of collegiate men's baseball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *Journal of athletic training.* Apr-Jun 2007;42(2):183-193.

4. Conte S, Requa R, Garrick J. Disability days in major league baseball. *The American Journal of Sports Medicine.* 2001;29(4):431-436.

5. Davis JT, Limpisvasti O, Fluhme D, et al. The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. The *American Journal of Sports Medicine* Aug 2009;37(8):1484-1491.

6. Calabrese GJ. Pitching mechanics, revisited. *International journal of sports physical therapy.* Oct 2013;8(5):652-660.

7. Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. The *American Journal of Sports Medicine.* Oct 2013;41(10):2430-2438.

8. Oyama S. *Effects of Trunk Movement on Pitching Biomechanics and Performance in High School Baseball Pitchers*. UMI: Human Movement Science, University of North Carolina, Chapel Hill; 2012.

9. Nicholls R, Fleisig G, Elliott B, Lyman S, Osinski E. Accuracy of qualitative analysis for assessment of skilled baseball pitching technique. *Sports biomechanics / International Society of Biomechanics in Sports.* Jul 2003;2(2):213-226.

10. Zaremski JL, Krabak BJ. Shoulder injuries in the skeletally immature baseball pitcher and recommendations for the prevention of injury. *PM & R : the journal of injury, function, and rehabilitation.* Jul 2012;4(7):509-516.

11. Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine and science in sports and exercise.* Nov 2001;33(11):1803-1810.

12. Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005-2007. *Pediatrics.* Jun 2008;121(6):1181-1187.

13. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *The American Journal of Sports Medicine.* Jul-Aug 2002;30(4):463-468.

14. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of biomechanics.* Dec 1999;32(12):1371-1375.

15. Taylor DC, Krasinski KL. Adolescent shoulder injuries: consensus and controversies. *The Journal of bone and joint surgery. American volume.* Feb 2009;91(2):462-473.

16. Keeley DW, Hackett T, Keirns M, Sabick MB, Torry MR. A biomechanical analysis of youth pitching mechanics. *Journal of pediatric orthopedics.* Jun 2008;28(4):452-459.

17. Fleisig G. Biomechanics of Baseball Pitching: Implications for Injury And Performance. *XXVIII International Symposium of Biomechanics in Sports.* July 2010 2010:46-50.

18. Nissen CW, Westwell M, Ounpuu S, Patel M, Solomito M, Tate J. A biomechanical comparison of the fastball and curveball in adolescent baseball pitchers. *The American Journal of Sports Medicine.* Aug 2009;37(8):1492-1498.

19. Rodosky MW, Harner CD, Fu FH. The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. *The American Journal of Sports Medicine.* Jan-Feb 1994;22(1):121-130.

20. Fleisig GS, Kingsley DS, Loftice JW, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *The American Journal of Sports Medicine.* Mar 2006;34(3):423-430.

21. Braun S, Kokmeyer D, Millett PJ. Shoulder injuries in the throwing athlete. *The Journal of bone and joint surgery. American volume.* Apr 2009;91(4):966-978.

22. Seroyer ST, Nho SJ, Bach BR, Bush-Joseph CA, Nicholson GP, Romeo AA. The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports health.* Mar 2010;2(2):135-146.

23. Rice SG, Congeni JA. Baseball and softball. *Pediatrics.* Mar 2012;129(3):e842-856.

24. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *The Journal of orthopaedic and sports physical therapy.* Feb 2009;39(2):90-104.

25. Fleisig G, Chu Y, Weber A, Andrews J. Variability in baseball pitching biomechanics among various levels of competition. *Sports biomechanics / International Society of Biomechanics in Sports.* Mar 2009;8(1):10-21.

26. Dun S, Loftice J, Fleisig GS, Kingsley D, Andrews JR. A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? *The American Journal of Sports Medicine.* Apr 2008;36(4):686-692.

27. Nissen CW, Westwell M, Ounpuu S, et al. Adolescent baseball pitching technique: a detailed three-dimensional biomechanical analysis. *Medicine and science in sports and exercise.* Aug 2007;39(8):1347-1357.

28. Wasserlauf BL, Paletta GA, Jr. Shoulder disorders in the skeletally immature throwing athlete. *The Orthopedic clinics of North America.* Jul 2003;34(3):427-437.

29. Han KJ, Kim YK, Lim SK, Park JY, Oh KS. The effect of physical characteristics and field position on the shoulder and elbow injuries of 490 baseball players: confirmation of diagnosis by magnetic resonance imaging. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine.* Jul 2009;19(4):271-276.

30. Weiss JM, Arkader A, Wells LM, Ganley TJ. Rotator cuff injuries in adolescent athletes. *Journal of pediatric orthopedics. Part B.* Mar 2013;22(2):133-137.

31. Rizio L, Uribe JW. Overuse injuries of the upper extremity in baseball. *Clinics in sports medicine.* Jul 2001;20(3):453-468.

32. Sabick MB, Kim YK, Torry MR, Keirns MA, Hawkins RJ. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *The American Journal of Sports Medicine.* Nov 2005;33(11):1716-1722.

33. Axe MJ, Snyder-Mackler L, Konin JG, Strube MJ. Development of a distance-based interval throwing program for Little League-aged athletes. *The American Journal of Sports Medicine.* Sep-Oct 1996;24(5):594-602.

34. McFarland EG, Ireland ML. Rehabilitation programs and prevention strategies in adolescent throwing athletes. *Instructional course lectures.* 2003;52:37-42.

35. Gregory B, Nyland J. Medial elbow injury in young throwing athletes. *Muscles, ligaments and tendons journal.* Apr 2013;3(2):91-100.

36. Hennrikus WL. Elbow disorders in the young athlete. *Operative Techniques in Sports Medicine.* Jul 2006;14(3):165-172.

37. Ireland ML, Andrews JR. Shoulder and Elbow Injuries in the Young Athlete. *Clinics in sports medicine.* Jul 1988;7(3):473-494.

38. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* Mar 1977;33(1):159-174.