MEASUREMENT OF SHOULDER RANGE OF MOTION, VIDEO ANALYSIS OF PITCHING, AND COMPARISON OF SHOULDER TREATMENTS IN HIGH SCHOOL BASEBALL PITCHERS WITH AND WITHOUT SHOULDER PAIN

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN THE GRADUATE SCHOOL OF THE

TEXAS WOMAN'S UNIVERSITY

DEPARTMENT OF PHYSICAL THERAPY

COLLEGE OF HEALTH SCIENCES

BY

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DENTON, TEXAS

MAY 2022

DEDICATION

For my family,

Thank you for your love and support.

ACKNOWLEDGEMENTS

I would like to gratefully acknowledge the many individuals and organizations that contributed to this dissertation. I would like to thank Dr. Alex Ortiz for his guidance in establishing my topic. I would like to thank Dr. Toni Roddey for her guidance during my data collection and writing. I would like to thank my committee chair, Dr. Katy Mitchell, for assisting in the final and perhaps most difficult phases. I would like to thank Jason DeGroodt for the many hours of data collection. I am grateful for the many individuals and organizations that allowed me to recruit research participants including Jason Washburn of College Park High school, Ricky Peña of Frassati Catholic School, Brent Maxwell of Caney Creek High school, and Angel Romero of the World Baseball Academy. Thank you to Ron Wolforth and Jonathan Massey of the Texas Baseball Ranch for the knowledge I have gained from you in working with baseball pitchers, recruiting participants, and your dedication to reducing arm injuries for baseball pitchers. Thank you to all of the research participants willing to spend their time and for their contribution toward reducing throwing-related arm injuries. I am grateful for the faculty, staff, and the Physical Therapy PhD program at Texas Woman's University. I would like to thank my parents for instilling a work ethic that has served me throughout my life. Finally, I would like to thank my wife and children for their understanding and support while working on my degree.

ABSTRACT

ANDREW ARTHUR

MEASUREMENT OF SHOULDER RANGE OF MOTION, VIDEO ANALYSIS OF PITCHING, AND COMPARISON OF SHOULDER TREATMENTS IN HIGH SCHOOL BASEBALL PITCHERS WITH AND WITHOUT SHOULDER PAIN

MAY 2022

Purpose: The purpose of this study was to evaluate shoulder range of motion, throwing biomechanical differences, and treatment protocols for high school baseball pitchers with and without the presence of throwing-related shoulder pain. Participants: Eighty participants were assessed for shoulder range of motion, 78 for baseball pitching biomechanics, and 38 completed a two-week treatment protocol. Methods: The participants with signed informed consent that met criteria were taken through passive shoulder range of motion measurements for internal and external rotation in the 90/90 position, and video analysis of throwing to measure maximum external rotation, trunk rotation timing, and trunk flexion. The participants reporting the presence of throwing-related shoulder pain were placed in one of four treatment protocols: 1. Self-stretching, 2. Posterior mobilization of the shoulder and manual stretching by a physical therapist, 3. The same treatment as protocol two with the addition of three throwing drills, 4. Only the three throwing drills. Data analysis was performed with SPSS statistical software version 25. A point-biserial correlation and independent samples *t*-test were run to determine if a relationship existed between shoulder range of motion and the presence of throwing-related shoulder pain. An independent samples *t*-test was run to determine if there was a difference in throwing mechanics between participants with and without the presence of throwing-related shoulder pain. A split-plot ANOVA was run to determine within subject differences for pre and post measurements and between subject differences for the four treatment groups. Results: This study found that participants reporting the presence of throwing-related shoulder pain had less internal rotation in the 90/90 position. This study also found no differences in baseball pitching biomechanics between high school baseball pitchers with and without the presence of throwing-related shoulder pain. The results of the treatment protocols showed improvement of GIRD, no change in pitching biomechanics, and reduction of pain level in protocols 1-4. Conclusion: GIRD was found in a group of high school baseball pitchers with throwing-related shoulder pain. Treatment with self-stretches and manual therapy showed significant improvement in GIRD and shoulder pain level.

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CHAPTER I

INTRODUCTION

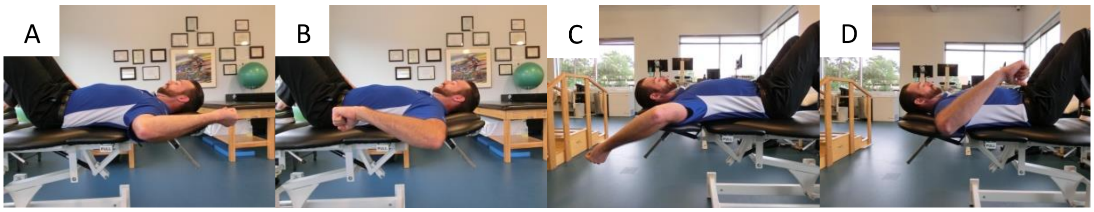
INTRODUCTION

High school is a unique time for baseball pitchers when there is often added pressure to perform in order to obtain a college scholarship or professional contract. High school baseball pitchers are being challenged to throw more and perform at their best during a time when many have not reached full musculoskeletal maturity. Throwing-related shoulder injury among high school baseball pitchers has not gone unnoticed, and yet, there is more evidence reported in the literature for college and professional level pitchers. There is anecdotal evidence that many high school baseball pitchers continue to throw with shoulder pain, but they do not develop an injury that keeps them from participating until reaching college or professional level baseball. In a 10-year study of serious injury among baseball pitchers, Fleisig et al discussed previous research that was focused on arm pain as a predictor of eventual serious injury.[1] Unfortunately, by the time the injury is recognized it is often too late to be able to intervene without a surgery that does not guarantee a full recovery and full return to competition. In order to make a significant impact on throwing-related shoulder injuries, baseball pitchers at the high school level should be assessed to identify developing problems before significant structural damage occurs.

Epidemiological studies of baseball players have reported the highest injury rate is to the shoulder of pitchers.[2-10] According to a study by Krajnik et al looking at injury rates in baseball and softball from 2005 through 2008 at approximately 74 high schools, the injury rate to the shoulder of baseball pitchers was 1.72 per 10,000 athlete exposures (one practice or game) and accounted for 38% of the total reported injuries.[3] Baseball pitchers also accounted for 73% of shoulder injuries requiring surgical intervention. In a 16-year study of injuries in collegiate baseball, 907 throwing-related injuries to the shoulder were reported with 73% occurring in baseball pitchers.[6] The shoulder injuries reported for high school and collegiate baseball pitchers included muscle-tendon strains, incomplete tears, and tendonitis.[2,3,6] Similar injury rates have been reported for professional baseball pitchers, with 28% of all injuries to pitchers occurring at the shoulder joint.[8] The American Sports Medicine Institute in Birmingham, Alabama noted a sharp increase in the early 2000s for surgical procedures of the shoulder in high school and collegiate pitchers due to pitching-related injuries.[9] Shoulder injury incidence rates for all age groups and levels of baseball pitchers is an important issue in the sports medicine community with further research needed to develop strategies to reduce injury.

Shoulder range of motion adaptation in baseball pitchers has been well documented in the literature.[23-47] There is agreement among researchers that it is common for baseball pitchers to gain external rotation and lose internal rotation of the dominant shoulder (see Figure 1) in the functional throwing position (90° of shoulder abduction and 90° of elbow flexion).[11-19] Two major areas of study evaluating the relationship between shoulder range of motion and shoulder injury have been through evaluating glenohumeral internal rotation deficit (GIRD) and total arc (TA). GIRD is the difference between dominant and non-dominant shoulder internal rotation measured in the functional throwing position. TA is the addition of shoulder external and internal rotation in the functional throwing position comparing dominant and non-dominant shoulders. Research studies in professional baseball pitchers have reported a range of acceptable cutoff points for GIRD between 5° and 18° while the acceptable cutoff for TA difference is 5°.[23,24] In a study of 11 collegiate baseball players, participants with pathologic internal shoulder impingement demonstrated an average loss of 19.7° of internal rotation while a group of asymptomatic college baseball players demonstrated an average loss of 11.1°.[30] In a study by Hurd et al, 210 asymptomatic high school baseball pitchers were evaluated for shoulder external and internal rotation range of motion in the functional throwing position.[31] This study reported an average gain of 10° of shoulder external rotation and an average loss of 15° of shoulder internal rotation, with standard deviation of 11°. Many of the pitchers in this study exceeded the acceptable cutoff points for both GIRD and TA but were asymptomatic at the time of the study. To date, the relationship between shoulder range of motion and shoulder pain has not been studied in high school baseball pitchers, and it is possible that the acceptable cutoff for TA and GIRD should be adjusted for this age group. In addition, there have not been any studies assessing the relationship of GIRD and TA with shoulder injury in high school baseball pitchers. Further study of the relationship between shoulder range of motion and shoulder pain in high school baseball pitchers is necessary to understand potential developing problems in this age group.

Figure 1. Positions for Assessment of Shoulder Range of Motion



A Non-dominant shoulder external rotation, B non-dominant shoulder internal rotation, C dominant shoulder external rotation, and D dominant shoulder internal rotation. Note the shift of range of motion toward external rotation on the dominant shoulder of a right-handed pitcher.

Research studies investigating treatment in the presence of GIRD in throwing athletes have focused on various stretching protocols that isolate the posterior and inferior capsule of the glenohumeral joint.[77-82] In a research study of 28 collegiate baseball players who underwent a 12-week stretching program, internal rotation improved an average of 5° on the dominant shoulder ($p = 0.04$).[78] The stretching program was performed daily and included six different stretches focusing on the posterior and inferior capsule of the shoulder. In a systematic review of six studies for the treatment of persons with GIRD utilizing various stretches for the posterior and inferior shoulder capsule, all of the studies reported significant increases in glenohumeral internal rotation.[77] The studies reviewed included persons with ages ranging from 18-38 years. The participants included baseball players, baseball pitchers, and a mixture of athletes and non-athletes. The results of this systematic review found that a variety of stretching protocols across multiple populations were effective for improving glenohumeral internal rotation. No study to date has been conducted for treatment in high school baseball pitchers with GIRD and throwing-related shoulder pain.

The biomechanics of overhand throwing have been studied with 3D motion capture systems that provide reliable and valid measurement for the kinetics and kinematics of throwing. Biomechanical research utilizing 3D motion analysis has been conducted for asymptomatic and symptomatic baseball pitchers from youth to professional level with emphasis on understanding throwing mechanics that may lead to injury.[48-53] Some of the throwing parameters studied include maximum shoulder external rotation, trunk rotation, and trunk flexion. Maximum shoulder external rotation has been reported to have a direct relationship with anterior force at the glenohumeral joint and possible implications for injury.[70] Aguinaldo et al reported that professional level baseball pitchers demonstrated a later onset of peak trunk rotation timing and discussed the likelihood of late trunk rotation reducing stress on the arm.[73] Fleisig et al reported that trunk flexion was significantly higher for higher skill levels when comparing youth, high school, collegiate, and professional level pitchers.[83] Trunk flexion has also been identified as a factor with an inverse relationship to joint torques in the upper extremity.[57] Pitchers with less trunk flexion at ball release and during follow through have shown greater joint torques of the upper extremity. Comparison of kinematic parameters in high school baseball pitchers with and without shoulder pain may identify throwing biomechanics related to injury.

Three-dimensional motion analysis is not readily available in clinical practice, but other technologies have been developed that make motion analysis of complex, high speed movements such as baseball pitching more accessible. Dartfish Pro Suite Video Analysis Software (Dartfish USA, Inc) is among the technologies available for motion analysis of video recordings and includes functions that have been shown to be reliable (ICC = .803-.986).[76] Motion analysis for baseball pitching mechanics is an important part of injury treatment and prevention. Research into the reliability of 2D video analysis for kinematic parameters would make a standardized assessment of throwing biomechanics more accessible.

The matter of throwing-related shoulder injury among baseball pitchers of all age groups and skill levels has been a growing concern for the sports medicine community. Researchers have responded by studying multiple topics proposed to be associated with shoulder injury. Much of the research has been specific to collegiate and professional level pitchers. It is hypothesized that high school level pitchers possess many of the problems associated with increased injury risk, but the players have not developed the structural damage that limits their ability to throw. Research involving high school baseball pitchers may be useful to detect mechanical problems earlier and make recommendations for injury prevention.

PURPOSE

The purpose of these studies was threefold: 1a. To determine the relationship between TA and the presence of throwing-related shoulder pain in high school baseball pitchers; 1b. to determine the relationship between GIRD and the presence of throwing-related shoulder pain in high school baseball pitchers; 1c. to determine if there was a difference in TA and GIRD between high school baseball pitchers with and without the presence of throwing-related shoulder pain; 2. To identify biomechanical differences using Dartfish video analysis in the throwing motion of high school baseball pitchers with and without the presence of throwing-related shoulder pain; 3. To compare four treatment protocols for correction of GIRD, reduction of throwing-related shoulder pain, and improvement of throwing biomechanics in high school baseball pitchers with throwing-related shoulder pain.

SPECIFIC AIMS AND HYPOTHESES

The first study had four aims: 1. To determine the relationship between TA and the presence of throwing-related shoulder pain in high school baseball pitchers; 2. To determine the relationship between GIRD and the presence of throwing-related shoulder pain in high school baseball pitchers; 3. To determine if there was a difference in TA between high school baseball pitchers with and without the presence of throwing-related shoulder pain; 4. To determine if there was a difference in GIRD between high school baseball pitchers with and without the presence of throwing-related shoulder pain. The hypotheses for Aims 1 and 2 were that TA and GIRD demonstrated good relationships ($r \geq 0.70$ per Portney and Watkins criteria)[85] with the presence of throwing-related shoulder pain in high school baseball pitchers. The hypotheses for Aims 3 and 4 were that TA and GIRD would be significantly greater ($p < 0.05$) for high school baseball pitchers with the presence of throwing-related shoulder pain than for those without.

The second study had three aims: 1. To determine if there was a difference in maximum shoulder external rotation during throwing between high school baseball pitchers with and without the presence of throwing-related shoulder pain using 2D video analysis; 2. To determine if there was a difference in trunk rotation timing during throwing between high school baseball pitchers with and without the presence of throwing-related shoulder pain using 2D video analysis; 3. To determine if there was a difference in trunk flexion at ball release during throwing between high school baseball pitchers with and without the presence of throwing-related shoulder pain using 2D video analysis. The hypotheses for the three aims were that high school baseball pitchers with the presence of throwing-related shoulder pain would have significantly lower maximum shoulder external rotation values ($p < 0.05$), shorter trunk rotation timing ($p < 0.05$), and lower trunk flexion values ($p < 0.05$).

The third study had three aims: 1. To evaluate and compare four treatment protocols for the correction of glenohumeral internal rotation deficit; 2. To evaluate and compare four treatment protocols for improvement of throwing biomechanics in high school baseball pitchers with throwing-related shoulder pain; 3. To evaluate and compare four treatment protocols for the reduction of throwing-related shoulder pain. The hypotheses were 1. There will be a significant difference among the four groups regardless of time on the assessment of GIRD, throwing biomechanics, and shoulder pain level; 2. There will be a significant difference between time 1 and 2 regardless of group on the assessment of GIRD, throwing biomechanics, and shoulder pain level; 3. There will be a significant interaction between group and time on the assessment of GIRD, throwing biomechanics, and shoulder pain level.

METHODS

Study One: Comparison of Shoulder Range of Motion in High School Baseball Pitchers With and Without the Presence of Throwing-Related Shoulder Pain

Participants. Eighty male high school baseball pitchers aged 15 to 18 years old were recruited for this study; forty-two participants (age, 16.33 ± 1.13 years) reporting the presence of throwing-related shoulder pain and thirty-eight participants (age, 16.52 ± 1.07 years) that reported being asymptomatic for at least four weeks prior to the study for an age-matched control group. The sample size was determined with G*Power 3.1.9.2 using a one-tailed *t*-test, alpha level 0.05, effect size 0.3 and power of 0.80. Participants included those with the primary position of pitcher with at least two years of competitive pitching experience. Participants were excluded if they had any surgery on the throwing arm that may alter shoulder range of motion. Participants were also excluded if they had not been throwing within 48 hours of the time of measurement to avoid range of motion changes from lack of throwing.

Procedures. The participants were recruited by word of mouth through affiliations of the lead researcher with area high schools and baseball organizations. Participants and parents read and signed assent and informed consent forms, respectively, approved by Texas Woman's University Institutional Review Board (IRB). A questionnaire was given to determine whether participants met criteria for the study. For the purpose of this study, throwing-related shoulder pain was determined as shoulder pain that originated from and was most intense when throwing a baseball and shoulder pain that limited usual throwing volume but did not keep them from participating. The participants that met criteria for the study were taken through a single session for measurement of dominant and non-dominant shoulder range of motion (see Figure 2) in a similar manner reported in previous research.[30-36] The measurements were taken at least two hours after any sustained activity involving the shoulder and no warm-up was performed prior to measurement. A researcher positioned the participant in supine with the arm in the functional throwing position, stabilized the scapula and rotated the shoulder into external rotation until the first capsular end feel was noted. A second researcher took measurements using a standard bubble goniometer. The shoulder was then rotated back to neutral and the procedure was repeated two more times for glenohumeral external rotation for a total of three measurements. The same procedure was repeated for glenohumeral internal rotation and both measurements were repeated for the other shoulder.

Figure 2. Two-Person Measurement of Passive Glenohumeral Range of Motion

Internal rotation (image on the left) and external rotation (image on the right).

Data analysis. The three measurements for shoulder external rotation and internal rotation of the dominant and non-dominant arm were entered into an excel spreadsheet for calculation of TA and GIRD. The mean of the three values was transferred into SPSS statistical software v.25. The data set was analyzed for outliers, normality, and equal variances to ensure there were no violations of the assumptions needed for statistical analysis. A point-biserial correlation was performed to determine if there was a relationship between total arc range of motion and the presence of throwing-related shoulder pain. A second point-biserial correlation was performed to determine if there was a relationship between glenohumeral internal rotation deficit and the presence of throwing-related shoulder pain. Two separate independent *t*-tests were performed to determine if there was a difference in mean total arc and mean glenohumeral internal rotation deficit between high school baseball pitchers with and without the presence of throwing-related shoulder pain, alpha set at 0.05 for each test.

Study Two: Comparison of Pitching Biomechanics in High School Baseball Pitchers With and Without the Presence of Throwing-Related Shoulder Pain

Participants. Seventy-eight male high school baseball pitchers from Study 1 also participated in Study 2; forty-two participants (age, 16.33 ± 1.13 years) reporting the presence of throwing-related shoulder pain and thirty-six participants (age, 16.52 ± 1.07 years) that reported being asymptomatic for at least four weeks prior to the study for an age-matched control group. The sample size was determined with G*Power 3.1.9.2 using a one-tailed *t*-test, alpha level 0.05, effect size 0.3, and power of 0.80. The same inclusion and exclusion criteria utilized for Study 1 including the questionnaire was also utilized for Study 2.

Procedures. The participants were taken through a throwing specific dynamic warm-up including calisthenics, tubing exercises and throwing to prepare for six maximum effort throws. A digital camera (Casio Exilim EX-ZR700, Casio Computer Co, LTD) with capture rate of 480 frames per second was set up on a tripod with 360º level 10 feet from the participant on their throwing side for the first two kinematic parameters and glove side for the third parameter. The camera position and beginning throwing position were marked to ensure consistent set up for data collection. Six throws at maximum effort were recorded, three on the glove side and three on the throwing arm side, while measuring throwing velocity with Pocket Radar (Santa Rosa, CA) to ensure maximum effort. Dartfish ProSuite Video Analysis software was used for measurement of the three kinematic parameters. In the late cocking phase, maximum shoulder external rotation was measured from neutral to the last point of external rotation prior to the frame of visible transition into internal rotation (see Figure 3). Trunk rotation timing was measured as the number of time units from maximum trunk rotation toward the throwing arm side to the frame just prior to visible release of the baseball (see Figure 4). Trunk flexion was measured as the angle created from the lateral midline of the thigh and lateral midline of the trunk with apex at the visible axis of rotation of the hip joint (see Figure 5). The three throwing parameters were chosen for this study because of identification in previous research for their relationship with injury.[64,65,70,71] The three measurements for each parameter were averaged for data analysis.

Figure 3. Maximum External Rotation Angle Measured in Degrees With Dartfish ProSuite

Figure 4. Trunk Rotation Timing Measured With Time Lapse in Dartfish ProSuite

Point of first foot contact (picture on the left) to ball release (picture on the right)

Figure 5. Trunk Flexion Angle Measured in Degrees With Dartfish ProSuite

Data analysis. Assumption of normality, homogeneity of variance tests and descriptive statistics were run for the data set. The three kinematic parameters were not correlated ($r < 0.70$), so three separate independent samples *t*-tests were run to compare each of the three biomechanical parameters between pitchers with and without the presence of throwing-related shoulder pain. The alpha level was divided by 3 for a p value of .017 to maintain power for the statistical analysis.

Study Three: Evaluation of Four Treatment Protocols for Correction of GIRD, Throwing Biomechanics, and Pain Level in High school Baseball Pitchers With Throwing-Related Shoulder Pain

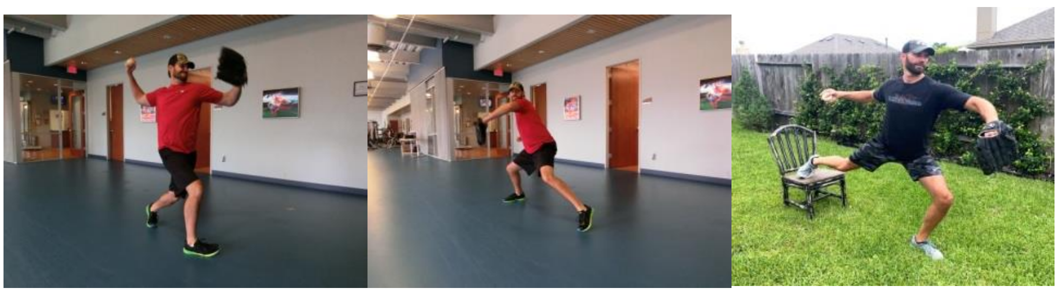
Participants. Thirty-eight of the participants (age, 16.50 ± 1.05) from Studies 1 and 2 that reported the presence of throwing-related shoulder pain completed Study 3. The sample size was determined with G*Power 3.1.9.2 using repeated measures ANOVA, alpha level 0.05, effect size 0.3 and power of 0.80. The same inclusion and exclusion criteria from Studies 1 and 2 including the questionnaire were utilized in Study 3.

Procedures. The procedure for recruitment of participants, consents and IRB approval were the same as for Study 1. For the purpose of this study, throwing-related shoulder pain was determined as shoulder pain that originated from and was most intense when throwing a baseball and shoulder pain that limited usual throwing volume but did not keep them from participating. This study included a total of eight sessions. The data for the initial session included measurement for GIRD from Study 1, measurement of three biomechanical parameters from Study 2, and report of shoulder pain level during the most recent throwing session using the 10-point numeric pain rating scale. There were six treatment sessions over the course of two weeks and a final measurement session one to two days after the last treatment session. The final measurement session included measurement for glenohumeral internal rotation on the dominant and non-dominant shoulders, a throwing session with 2D video analysis to measure the same three biomechanical parameters, and throwing-related shoulder pain level. The participants were randomized to one of four groups whereby participant one went into Group 1, participant 2 into Group 2, and so on until N = 10 for each group was achieved. Group 1 performed a shoulder-specific warm-up consisting of light tubing resistance exercises followed by supervised self-stretches of three sets of thirty second holds for shoulder internal rotation and horizontal adduction. Group 2 performed the same shoulder specific warm-up followed by five sets of progressive oscillation manual therapy posterior shoulder mobilizations performed by a physical therapist and three sets of thirty second holds of manual therapy stretching performed by a physical therapist for shoulder internal rotation and horizontal adduction. Group 3 performed the same shoulder specific warm-up followed by five sets of progressive oscillation manual therapy posterior shoulder mobilizations performed by a physical therapist, three sets of thirty second holds for internal rotation stretching and horizontal adduction stretching also performed by a physical therapist. Group 3 also performed a throwing specific dynamic warm-up followed by ten throws each of three throwing drills specific to the biomechanical parameters being assessed. Group 4 performed both the shoulder specific and throwing specific warm-ups followed by ten throws each for the same three throwing drills used for Group 3. The types of stretches including sets and durations were performed in a similar manner to those reported in previous research studies.[20-23]

See Figure 6 for the stretches described in the procedures above. The throwing drills were chosen for their relationship to the throwing biomechanical parameters assessed. See Figure 7 for the throwing drills.

Figure 6. Shoulder Stretches and Mobilization

Figure 7. Throwing Drills



From left to right external rotation drill, trunk rotation timing drill, trunk flexion drill for isolation and improvement specific to each biomechanical parameter.

Data analysis. Assumption of normality, homogeneity of variance tests and descriptive statistics were run for the data set. The outcome variables were not correlated ($r < 0.70$), so five separate split-plot ANOVA tests were calculated to determine within subject differences for pre and post measurements and between subject differences for the four treatment groups. The alpha level was divided by five for a p value of .01 to maintain power for the statistical analysis.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

Arm injuries among baseball pitchers are highly prevalent at all levels of the sport[1,8] with the highest incidence occurring at the shoulder.[1-10] Multiple studies have reported that the shoulder is more at risk from throwing-related injury due to the high velocity and extreme range of motion that occurs at the glenohumeral joint.[2-4,6] There is also agreement among these researchers that cumulative microtrauma to the shoulder due to the repetitive nature of throwing is the most common mechanism for shoulder pain and injury among baseball pitchers.[2-4,6] Shoulder injury is the most common reason that participation time is lost among pitchers, is responsible for the highest rate of surgery among baseball pitchers, and has also been estimated to cost Major League Baseball (MLB) half a billion dollars each year.[7] The issue of shoulder injury among baseball pitchers affects all ages and skill levels and may be the reason that some are unable to advance to the next level and continue playing the sport they enjoy. There has been increased attention to arm injuries among baseball pitchers over the past 20 years with recommendations for ways to prevent injury,[10] but research indicates that shoulder injury is still common, and the injury rate is increasing.[20]

In a landmark study by Lyman et al in the early 2000s, attention was called to multiple risk factors for shoulder and elbow injuries in a longitudinal study of youth baseball pitchers.[8] The results from this study influenced rule changes for youth baseball organizations such as USA Baseball to limit pitch counts in an effort to reduce the number of arm injuries. Since that time further study and discussion have helped to shape guidelines for youth pitchers with prevention of arm injuries as the primary focus. Much of the study of youth pitchers is based on surveys that looked at the relationship of pain and injury with external factors such as number of pitches thrown, types of pitches thrown, playing other positions, etc. There is limited research on the physical and biomechanical factors among youth pitchers that may increase risk for injury. Two populations have been the primary focus of previous research studies related to baseball pitchers: collegiate and professional level. Since these athletes are no longer minors and they are accessible to athletic trainers and other health care professionals, recruitment of these participants has been easier. There is also pressure to return these paid athletes as soon as possible to avoid money lost. The available peer-reviewed research for baseball pitchers is lowest for the population of high school baseball pitchers; however, this population has the potential to provide crucial information toward throwing-related arm injuries that are developing but have not reached the point of limiting throwing and participation.

This literature review was started in 2013 with regular updates and completion in 2021. It was noted throughout the review that more research was available for youth, collegiate, and professional level baseball pitchers with fewer articles for high school level athletes. The primary focus of the literature review was on high school baseball pitchers, but also included all ages and skill levels to gain a better understanding of throwing-related injuries. All databases available through Texas Woman's University library were searched and articles were placed into the following categories: incidence of arm injury among high school baseball players, incidence of arm injury among collegiate baseball players, shoulder pathology and surgery rate among professional baseball players, types of injury among baseball pitchers, risk factors for shoulder injury among baseball pitchers, shoulder range of motion changes and injury among baseball pitchers, shoulder range of motion adaptation among asymptomatic baseball pitchers, reliability and validity of 2D motion analysis, baseball pitching biomechanics, treatment for shoulder pain/injury among baseball pitchers, and training baseball pitching biomechanics.

INCIDENCE OF ARM INJURY AMONG HIGH SCHOOL BASEBALL PLAYERS

There are approximately 5 million participants in baseball between the ages of 6 and 17 years old[1] with 486,567 participating at the high school level, and approximately one-fourth of those high school baseball players that will pitch.[2,3] In a study by Krajnik et al, an internet-based surveillance system RIO (reporting information online) was utilized to collect injury data for United States high school baseball players from 2005 to 2008.[2] High schools were included that had at least one certified athletic trainer (ATC) with valid email address and categorized based on region and size. For this study, injury was defined as any injury that occurred during practice or competition, required medical attention, and resulted in at least one additional day of restriction from participation beyond the day of the injury. An athlete exposure (AE) was defined as one practice or competition. The ATC assigned to the study would report injuries for AEs including body site, diagnosis, and injury mechanism with access to review and update throughout the study. Injuries were calculated as a ratio to each 10,000 AEs and additional comparisons were made between injury risk factors utilizing rate ratios (RR) and injury proportion rates (IPR), ie, number of shoulder injuries in practice vs games.

Over the course of four baseball seasons, there were 91 shoulder injuries for an injury rate of 1.72 per 10,000 AEs.[2] The most common shoulder injury was muscle strain/incomplete tear (31%) and the majority of them occurred in practice (37%). Pitching was the most common mechanism of shoulder injury that required greater than 9 days off from participation (35%), and of those injuries to all players requiring more than 9 days off, 40% required surgery.[2] Eighty-one percent of baseball shoulder injuries were new injuries while 10% were recurring, with the majority of those sustained by pitchers. The majority of shoulder injuries that required surgery (73%) occurred among pitchers of which 80% were juniors or seniors. The diagnoses requiring surgery in order of most to least were torn cartilage, bursitis, dislocation and ligament sprain. Overuse and chronic injuries accounted for 36% of shoulder surgeries with 46% of those occurring to pitchers.[2] The majority of those injuries are classified as overuse, many of them reoccurring and some of them requiring surgery, so according to this research the largest impact for prevention of arm injuries among baseball players would be to target the shoulder of baseball pitchers.

In a research study for arm injuries among high school baseball players[1], the National High School Sports Related Injury Surveillance System used a high school RIO to track injuries from 2005-2006 to 2014-2015. One hundred high schools were included in the study that met criteria of having at least one nationally registered ATC with a valid email address. The ATCs were given access to report injuries that included demographics along with details about the injury. A reportable injury was one that 1. occurred as a result of participation in baseball practice or game, 2. required medical attention by an athletic trainer or physician, and 3. resulted in at least one day of missed participation in addition to the day of injury.[1] Demographics included age, height and weight; injury detail included side of the body, diagnosis and severity; injury event included mechanism of injury and activity at time of injury. Throughout the study, athletic trainers were allowed to review previous data and update as needed.

The statistical analysis for this study included injury rate based on number of injuries per AE. One athlete exposure was equivalent to participation in one practice or one game with rates based on number of injuries per 10,000 AEs. Injuries were also calculated for subgroup comparison as a RR or IPR that compared injury categories such as number of shoulder injuries during a game vs number of shoulder injuries during practice. From 2005-2006 through 2014-2015, athletic trainers reported 241 shoulder injuries and 150 elbow injuries in 1,734,198 AEs, for a shoulder injury rate of 1.39 per 10,000 AEs and an elbow injury rate of 0.86 per 10,000 AEs.[1] The injury rate for the shoulder was significantly higher than injury rate for the elbow with rate ratio of 1.61. The overall shoulder and elbow injury rates from 2005-2006 to 2014-2015 seasons remained relatively stable with no significant change for injury rates over that span of time. The injury rates for the shoulder and elbow were significantly higher in games when compared to practices with RR of 1.44 and 2.15 respectively. Most of the shoulder injuries (83.8%) and elbow injuries (84.7%) were new with the most common shoulder injury (31.3%) being muscle strain and the most common elbow injury (33.1%) being ligament sprain. The majority of shoulder and elbow injuries occurred to baseball pitchers with further comparisons made specifically to this group.

There was a significant difference in proportion of injuries reported in this study with arm injuries to baseball pitchers being much higher than any other position. Non-contact and overuse were the most common mechanisms of injury for the shoulder (93.5%) and elbow (88.0%) of high school baseball pitchers.[1] A greater proportion of shoulder injuries (38.7%) compared with elbow injuries (7.3%) were muscle strains, although the exact muscle or muscle group was not identified.[1] Compared with shoulder injuries (3.2%), a greater proportion of elbow injuries (42.7%) were ligament sprains although the exact ligament was not identified. More than half of the shoulder (77.5%) and elbow (61.8%) injuries occurred at the varsity level. Most shoulder (83.9%) and elbow (84.3%) injuries were new as opposed to recurrent injuries. Similar proportions of shoulder and elbow injuries were recurrent from the previous academic year (9.7% and 10.8%, respectively) or from the current academic year (5.4% and 4.8%, respectively). The majority of pitchers with shoulder (70.8%) and elbow (64.6%) injuries returned to play within 21 days. Elbow injuries more frequently resulted in removal from play for more than 3 weeks (25.3% vs 15.7%, respectively) or medical disqualification (11.4% vs 5.6%, respectively) compared with shoulder injuries, although these differences were not statistically significant. Shoulder injuries (10.8%) more frequently resulted in surgical treatment than elbow injuries (3.6%), but this difference was not statistically significant.[1]

Saper et al. completed the most comprehensive epidemiological study of injury among high school baseball players.[1] A 10-year period of athlete exposures was observed, and the researchers concluded that it is crucial for health-care providers to drive targeted evidence-based prevention strategies specific to shoulder and elbow injuries in this population. Saper et al. reported the overall injury rate to the shoulder was 1.39 per 10,000 AEs and injury rate to the elbow was .86 per 10,000 AEs.[1] The injury rate was significantly higher for the shoulder (1.39 per 10,000 AEs) than the elbow (.86 per 10,000 AEs). The injury rate to the shoulder (39.6%) and elbow (56.9%) of baseball pitchers was also significantly higher when taken as a percentage of all injuries to baseball players.[1] The number of injuries to the shoulder or elbow requiring surgery and the number of injuries requiring greater than one week off of participation were also highest for baseball pitchers.

Throwing-related arm injuries is an issue that needs attention from the sports medicine community.[1,2] There is agreement from Krajnik et al and Saper et al that shoulder injuries among baseball pitchers accounts for the majority of all injuries among high school baseball players, incurs the most time lost from participation, and has the highest number of surgical procedures.[1,2] The cause of these injuries is primarily throwing-related overuse. In this dissertation, shoulders of high school baseball pitchers were chosen for study in order to have the greatest impact on reduction of throwing-related arm injuries.

INCIDENCE OF ARM INJURY AMONG COLLEGE BASEBALL PLAYERS

College baseball experienced significant growth from the 1988-1989 academic year to the 2003-2004 academic year going from 668 schools to 867 schools and 19,670 participants to 27,672 participants.[5] Although low risk compared to other sports, baseball players are at risk for injury that may affect scholarships, possible professional baseball contracts, and even career aspirations. Dick et al described the epidemiology of collegiate men's baseball injuries from 1988-1989 through 2003-2004 seasons.[5] Data was gathered from the Injury Surveillance System (ISS) that was established in the National Collegiate Athletic Association (NCAA) in 1982 with a goal of providing a foundation for evidence-based decision making in regards to health and safety. For the ISS, a reportable injury was defined as one that occurred as a result of participation in an organized practice or competition, required medical attention by an ATC or physician, and resulted in restriction from participation for at least one additional day beyond the day of injury. An AE was defined as one student athlete participating in one practice or game with exposure to the possibility of athletic injury.

Over the 16-year period, 4,453 injuries from more than 58,000 games and 3,893 injuries from more than 75,000 practices were reported. In that same time period, 1,623 shoulder injuries were recorded, of which 972 (59.5%) were associated with throwing and pitching accounted for 709 (73.0%) of these injuries. The injury rate to the arm for all baseball players was 45% for all practice and game injuries. Non-contact mechanism of injury such as throwing or pulling a muscle accounted for 42% of the game injuries and 65% of practice injuries. One of the top injuries that resulted in at least 10 days off participation occurred to the shoulder or elbow during games and accounted for 14.3% of the total number of game injuries. The majority of severe injury for all baseball players during practices was to the shoulder. Elbow injuries accounted for 9.3% of game injuries and 10.8% of practice injuries with a total of 836 elbow injuries over the 16-year period, of which 593 (70.9%) were associated with throwing. Similar to other injury incidence studies in baseball,[1-4] non-contact arm injuries among pitchers had the highest injury rate when compared to non-contact injuries and other body regions for non-pitchers. Injury rates were also highest during games and thought to be related to players being more likely to "go all out." Non-contact injury rates to the arm were higher in pre-season practices, which may be attributed to lack of preparation and increased activity prior to the arm being prepared for it.[5]

Similar to findings for high school baseball players,[1,2] the most common injuries among collegiate baseball players occurred at the shoulder and elbow.[5] Throwing-related overuse injuries to the shoulder of baseball pitchers had the highest injury incidence among collegiate baseball players, which is also in agreement with findings for high school baseball players.[1,2] Non-contact injuries to the shoulder of baseball pitchers is an issue that affects high school and collegiate level players. There is potential to decrease injury incidence for both populations by reducing injury incidence at the high school level through further research for prevention strategies that may be utilized through college as well.

SHOULDER PATHOLOGY AND SURGERY RATE AMONG PROFESSIONAL BASEBALL PLAYERS

Information on injury incidence at the professional level is limited due to a central repository of injury data only recently being created.[7] The athletes playing in the MLB are spread out and treated by different surgeons, so a central database is well suited to study common shoulder pathologies and treatment for professional baseball players. Surgery for the shoulder of an overhead athlete is commonly the last resort with as many as one-third of those undergoing a surgical procedure that are unable to return to the sport.[7] Still, there were 542 MLB players that underwent shoulder procedures from 2012 to 2016. The first step toward reducing shoulder injury rates and improving treatment outcomes is to better understand the current pathologies and treatments. One study on epidemiology of shoulder surgery among professional baseball players emphasized the need for further research now that data is available through a central database.[7] This study by Chalmers et al was the first to perform a comprehensive analysis of the most commonly encountered shoulder pathologies and the most common shoulder procedures for professional baseball players.

The data collected for this study was any MLB player with history of a shoulder surgery between 2012 and 2016. Those included in the return to sport (RTS) portion of the study had to be greater than 2 years out from the date of surgery. The following information was collected for the participants: date of surgery, position, hand dominance, level of play, age, type of surgical procedure, history of shoulder surgery, prior time spent on the disabled list, and reason for prior time spent on disabled list.[7] The surgical procedures were classified based on structure (labrum, rotator cuff, biceps tendon, subacromial, capsule, chondral, acromioclavicular joint) and then further broken down as needed. Return to play information as well as to what level were also recorded.

This study reported a total of 581 shoulder procedures performed among 542 players between 2012 and 2016. There are approximately 250 professional baseball players for each team between major and minor league levels and approximately 7300 professional baseball players each year. The incidence of shoulder surgery was 1.48% per player-year and remained stable year to year. Pitchers were the most common player to have shoulder surgery and account for around 45% of the team but accounted for 60% of the shoulder surgeries. The percentage of shoulder procedures for major league versus minor league was 19% and 81%, respectively. Approximately 11% of all professional players were in the majors so the ratio of procedures between levels of play is similar. The majority of players that underwent surgery were between 20 and 25 years old. The incidence of shoulder surgery among professional baseball players is in agreement with previous research for injury incidence among baseball players that shoulder injury and more specifically shoulder injury among baseball pitchers is the highest.[7]

The types of shoulder procedures performed among baseball players were highest for the labrum (63%) and rotator cuff (34%). The types of shoulder procedures among baseball pitchers were similar with the labrum accounting for 51.7% and rotator cuff for 37.9%. The location of labrum pathology was posterior labrum 58%, anterior labrum 44%, superior labrum 27%, and inferior labrum 11% for all baseball players. Data for labrum pathology among baseball pitchers was not reported, but it is likely that the posterior and superior labrum (SLAP) would account for a higher percentage of labrum pathology due to the nature of throwing-related injuries. The rotator cuff pathology was the next most common location of injury with the supraspinatus (75%) being the most injured, followed by the infraspinatus (41%), then subscapularis (8%), and teres minor (1%). Other types of injuries included shoulder capsule, chondral surface, AC joint, biceps, and subacromial space.[7]

One of the issues reported in the literature is the difference in RTS for throwing-related arm injuries between the elbow and the shoulder. The RTS rate following shoulder procedures is consistently lower than those performed on the elbow.[7] The RTS rate reported in this study was 63% for all baseball players. The RTS rate was 55% for baseball pitchers and 76.4% for non-pitchers. The difference noted here is likely due to injuries to non-pitchers including acute trauma from a collision or fall with better outcome for RTS. Throwing-related injuries to the shoulder that require surgical intervention have been reported to have lower RTS rate than those that are not throwing-related. Of the players that were able to return to competition, 86% returned to their previous level of play. The number of days from the date of surgery to the first game at previous level was 381 ± 211 for pitchers and 287 ± 149 for non-pitchers.[7]

Research for injury incidence among high school and collegiate baseball players found that throwing-related arm injuries among all players is the highest, and the majority of those occur to the shoulder of baseball pitchers. Similar findings were found for professional level baseball players with the majority of arm injuries requiring surgical intervention occurring to the shoulder of baseball pitchers.[7] Injury incidence for professional baseball has been limited; although Chalmers et al reported an expected increase now that a central database has been made available. Still, there is agreement among researchers that the highest injury rates for baseball players from high school through professional is to the shoulder of baseball pitchers.[1-7] The greatest impact in reducing throwing-related arm injuries may be the development of injury prevention strategies beginning with the high school level that may be carried throughout a player's career.

TYPES OF SHOULDER INJURIES AMONG BASEBALL PITCHERS

The three phases of the baseball pitching delivery: late cocking, acceleration, and deceleration account for the majority of baseball pitching injuries.[26] The extreme degree of external rotation in the late cocking phase leads to anterior instability and posterior impingement of the shoulder. Both static and dynamic stabilizers are involved in resisting the extremes of motion and large forces at the shoulder with the potential of injury to muscle, ligament, shoulder capsule, labrum, and inferior surface of the acromion.

Common injuries among baseball pitchers include bicipital tendonitis, subacromial impingement, rotator cuff tears, and SLAP tears.[26]

Bicipital tendonitis is a common cause of shoulder pain among baseball pitchers.[23-26] There are multiple mechanisms proposed for injury to the long head of the biceps tendon (LHBT) including strain due to repetitive microtrauma during the phases of throwing when the biceps is active, friction of the biceps on the lesser tuberosity during maximum shoulder external rotation, and impingement in the coracoacromial arch due to anterior instability. The LHBT is active as an anterior stabilizer during maximum shoulder external rotation and through the majority of arm acceleration with a large amount of stress that over time may cause tendonitis. According to electromyography studies of throwing, the biceps is most active at the end of arm acceleration into ball release to decelerate elbow extension and forearm pronation.[26] The LHBT is especially susceptible to microtears during this portion of the throwing delivery, because it crosses two joints and is acting eccentrically. The excessive amount of shoulder external rotation during the late cocking phase brings the lesser tuberosity of the humerus toward the posterior aspect of the acromion causing a large amount of friction and strain to the LHBT nearly perpendicular to the bicipital groove. As the shoulder moves from external rotation into internal rotation during the end of arm acceleration, the greater tuberosity approximates the anterior portion of the acromion and the coracoacromial arch causing a similar stress to the LHBT perpendicular to the bicipital groove.[26]

Subacromial impingement is a common injury seen among baseball pitchers with overgrowth (spurring) of the inferior surface of the acromion that leads to narrowing of the subacromial space.[26,29,30] There is the potential for compression of the supraspinatus tendon, long head of the biceps tendon, and infraspinatus. The large amount of shoulder range of motion that occurs in the late cocking, acceleration and deceleration phases of throwing causes translation of the humeral head across the subacromial space in an anterior to posterior and posterior to anterior direction with friction of the previously mentioned soft tissue along with the subacromial bursa and the inferior surface of the acromion. There is potential for scarring of the subacromial bursa and development of osteophytes on the inferior surface of the acromion, which will further reduce the size of the subacromial space and increase compression of the soft tissue in that space. Partial tears of the supraspinatus, infraspinatus, and LHBT are common among baseball pitchers with the possibility of complete rupture although this is rare due to pain and dysfunction during throwing with partially torn and painful soft tissue.[26]

Rotator cuff tears are common among baseball pitchers due to the large amount of stress placed on them to decelerate the shoulder as it is moving into horizontal adduction and internal rotation during late acceleration, ball release, and follow through phases.[23,25,27] The shoulder also undergoes a large distraction force during these phases that the rotator cuff resists in order to maintain the humeral head in the glenoid fossa. The eccentric force that is placed on the rotator cuff during these last three phases of throwing causes microtraumatic tearing that accumulates over time with the repetitive nature of throwing.[27] Degeneration over years of throwing may lead to rotator cuff tears even without impingement that was discussed in the previous paragraph. The supraspinatus does not have good blood supply in the area where the tendon bends over the humeral head and attaches to the greater trochanter, which may also play a role in degenerative tears that do not heal well. The infraspinatus and teres minor are susceptible to tearing during the large distraction force at ball release and into follow through where these tendons are in line to act eccentrically to resist shoulder internal rotation and horizontal adduction. The rotator cuff is also susceptible to injury as they are smaller relative to the larger power generators such as the pectoralis major and latissimus dorsi, which are responsible for the majority of shoulder acceleration during throwing.[27]

The shoulder labrum aids in stability of the shoulder in all directions and may become compromised with the high force and large amounts of range of motion seen at the shoulder during throwing. Injury to the shoulder labrum of baseball pitchers occurs most often as a SLAP lesion.[23,24,27] There have been four types of SLAP tears defined: type I is fraying of the superior labrum with biceps tendon and labrum remaining attached to the superior glenoid, type II is fraying along with detachment of the superior labrum and biceps tendon from their attachment on the glenoid, type III is a bucket handle tear at the attachment of the superior labrum with the periphery and biceps tendon remaining intact, and type IV is a bucket handle tear extending into the biceps leaving portions of the labrum and biceps displaceable into the glenohumeral joint. Multiple mechanisms have been proposed for this injury with the likelihood that a combination of the translation of the humeral head and large amount of force through the LHBT causing a "peel back" of the labrum off of the glenoid. The humeral head translates anterior during the late cocking phase with the LHBT stabilizing the humeral head, which creates a pull from posterior to anterior through the attachment of the superior labrum and LHBT. A similar pull occurs once the arm is accelerated forward and the biceps acts eccentrically to decelerate the elbow and forearm. The large amount of stress through the biceps-labral complex during both the cocking phase and deceleration has been proposed by multiple researchers as the primary cause of SLAP tear among baseball pitchers.[23,27,30]

Several researchers have reported that throwing-related shoulder injuries occur due to the large amount of range of motion and high velocity of movement that occurs when throwing a baseball.[23,24,26-28] The number of throws at or near maximum effort that is common for baseball pitchers makes them particularly susceptible to certain injuries of the shoulder. Anterior instability and posterior stiffness of the shoulder is the primary mechanism for throwing-related shoulder injury.[26] The LHBT, rotator cuff, subacromion, and shoulder labrum are the most common structures to be injured among baseball players, and multiple researchers report shoulder range of motion changes as one of the potential causes of these injuries.[23,24,26-28] Therefore, this dissertation has focused on shoulder range of motion changes due to its relationship with many of the common throwing-related shoulder injuries.

RISK FACTORS FOR ARM INJURY AMONG BASEBALL PLAYERS

Participation in sports is beneficial to overall health, but it does carry with it risk of injury. Arm injuries among baseball pitchers is the most common injury among all baseball players, and it is believed to be caused by the dynamic overhand throwing motion used to pitch a baseball that causes cumulative microtraumatic stresses.[12-17] Arm injuries are typically divided into either shoulder or elbow injuries with shoulder injuries being the most prevalent. Student participation in all sports including baseball has increased over the past 20 years and with one-fourth of all baseball players pitching, the incidence of arm injuries is likely to increase as well.[1] The number of pitching-related surgeries for high school baseball pitchers has also increased, and has subsequent medical costs and money lost from a potential scholarship or professional contract although these numbers have not been reported for this age group.[14] There are many risk factors for throwing-related arm injuries supported by quality, peer-reviewed research.

One of the most influential research studies specific to baseball pitchers was conducted in Birmingham, Alabama from 1997-1998.[8] Data was collected over the course of two seasons on a total of 298 baseball pitchers between 9 and 12 years old. The study by Lyman et al was in response to parents and coaches throughout youth baseball organizations requesting information about pitch count and throwing breaking pitches among other factors with potential risk for arm injury among youth baseball pitchers. Although there was no empirical evidence at the time, speculation about pitch counts and pitch types along with biomechanical research into these factors was enough to make recommendations on pitch count limits and delaying throwing breaking pitches until older ages. Still, arm injuries persist and further research is necessary to understand the factors that increase risk.

Lyman et al investigated pitch counts (number per game and total for the season), breaking pitches (eg, curveball and slider), demographics, physical attributes, skill, and frequency of participation with comparison to reported arm pain.[8] The coaches participating in the study were given a pitch-count book with explicit instructions for tracking pitch counts (interrater reliability of pitch counts was perfect, r = 1.00, when compared to spot checks by research personnel).[8] The coaches also provided information for each pitcher and would let interviewers know those that pitched, so post-game interviews could be conducted specific to arm pain and performance. The pre-season interviews and post-game interviews for coaches and pitchers were used to record the following data: demographic characteristics (eg, age, height, weight), baseball participation (eg, years played, primary position played, baseball camp attendance), pitching history (eg, seasons pitched, pitching practice frequency, pitch types used), and game characteristics (eg, pitch count, self-satisfaction with performance, arm-related complaints). Interrater and intrarater reliability testing of questionnaire responses revealed kappa coefficients consistently over 0.80.[8]

The outcome measure of interest was throwing-related arm complaints specific to pain or soreness of the shoulder or elbow joint. Mild complaints were defined as pain in the elbow or shoulder joint without loss of league-sanctioned game or practice time. Minor complaints were defined as pain in the elbow or shoulder joint with loss of time pitching in the game in which the pain occurred. Moderate complaints were defined as pain in the elbow or shoulder joint with loss of time in a subsequent league-sanctioned game or practice session, visiting a physician for evaluation, or stopping pitching for 2 weeks or more during the season. Serious complaints were defined as cessation of pitching for the remainder of the season accompanied by physician evaluation and treatment. The categories for complaint of throwing-related arm pain or soreness were taken from a senior author for the Lyman study, Dr. James Andrews.[8]

The demographics for the participants of the study had a mean age of 10.8 years (range 8.1–12.4), mean height 4’9” (range 3’10” to 5’8”), and 87 pounds (range 50–179). Nearly 94% of the pitchers were right handed. A majority threw change-up pitches, and about one-third threw a curveball. Other pitches included were sinker, slider, or knuckle ball pitches, and accounted for 10% collectively. During follow-up, the 298 pitchers made 2699 pitching appearances, appearing in an average of 9 games (range 1–30) each. Each appearance averaged 2.4 innings (range 0–7) and 43 pitches (range 1–154). After each game pitched, study participants were asked to rate their pitching performance using a 5-point Likert scale (1 = poor; 5 = excellent). Pitchers classified more than 70% of their pitching appearances as either good or excellent performances.[8]

According to Lyman et al, the most commonly reported complaint was shoulder pain, which was reported by 32% of the pitchers (95 pitchers) in 7% of the pitching appearances (189 appearances).[8] Elbow pain was reported by 25.5% of the pitchers (19) in 4.5% of their pitching appearances (121 appearances). Elbow or shoulder pain was reported by 47% of the pitchers over the course of the 2-year study. More than 68% of elbow pain occurred on the medial side of the elbow. Nearly 29% of shoulder pain was in the superior aspect of the shoulder and approximately 20% was located in each of the anterior, posterior, and lateral aspects. The primary location for a report of other arm pain was the upper arm, which is interesting considering the likelihood of pain referred from the subacromial space down the lateral aspect of the arm. Many more shoulder pain complaints may have been missed as referred pain bringing the percentage of pitchers with shoulder pain even higher. More than 70% of all complaints were mild in nature. A total of 13 physician visits specific to throwing-related arm pain were reported. Approximately 10% of the pitchers had arm complaints, which may indicate that baseball pitchers rarely seek medical help for throwing-related arm pain.[8]

Lyman et al also reported that independent risk factors for elbow pain included increased age, increased weight and shorter height.[8] Throwing more than 600 cumulative pitches in games throughout a single season also increased risk. Other variables leading to an increase in injury risk for throwing-related elbow pain included a report of fatigue during the game, decreased self-satisfaction with performance, weightlifting, and playing baseball outside of the league. The number of cumulative pitches thrown before the game significantly reduced complaints of throwing-related elbow pain, so an increased number of warm-up throws appeared to be advantageous. The risk factors of the number of innings pitched and games pitched were not significantly associated with elbow pain.[8]

Complaints of throwing-related shoulder pain were evaluated for the same risk factors with every 10 pitches thrown resulting in significantly increased odds for shoulder pain. The number of game pitches thrown was categorized into 25-pitch increments with those throwing greater than 75 pitches per game 3.2 times more likely to experience shoulder pain than those who threw less than 25 pitches per game. Similar to complaints of elbow pain, cumulative pitches before the game had an inverse relationship with complaints of shoulder pain. Each inning pitched in a single game was associated with increased risk for shoulder pain. There was no significant association between complaints of shoulder pain and pitch type, which is contrary to conventional wisdom for baseball pitchers and one of the hypotheses for this study. Independent risk factors identified for shoulder pain among youth pitchers included increased pitches per game, decreased cumulative pitch total, arm fatigue, and lack of self-satisfaction with performance.[8]

There have been many risk factors identified through descriptive and narrative research reports, but there was not a systematic review looking at prospective studies until recently. In 2019, Agresta et al reported the results of a systematic review for only prospective cohort studies investigating risk factors for upper extremity injuries of baseball players.[12] Studies included baseball players at all levels from youth to professional and all positions with the reasoning that this would provide the best insight to risk factors for arm injury. The review excluded studies that did not include the upper extremity as well as those that included traumatic injury (eg, eye injury, face injury). Studies that assessed only pain rather than injury were also excluded with injury defined as some amount of time loss from play.

Agresta et al identified 14 articles that met their criteria.[12] Complete prospective analysis was conducted on a total of 559 professional baseball players (19 and older), 521 high school athletes (age range, 15-18), and 1346 youth athletes (age range, 7-14 years). The definition of injury varied across the studies reviewed for professional players with some researchers utilizing placement on the disabled list and others utilizing time lost from regularly scheduled work. At the high school and youth levels, 5 studies considered 1 day or missed event an injury, others used 8 or 10 days, and some used surgery or retirement to define injury. Three broad categories were used for risk factors including physical strength or structure, age, and throwing quantification. Most studies (10 out of 14) assessed structural or strength deficits in relation to injury with an emphasis on shoulder function. The remaining studies assessed throwing characteristics, pitch velocity, pitch type, pitch volume, age, position, and baseball experience. Only one qualifying study assessed throwing mechanics in relation to injury risk.[12]

The results of the systematic review identified several risk factors for upper extremity injuries among baseball players. One study indicated that risk of shoulder injury for youth athletes (aged 7-11 years) increased for pitchers and catchers, for those that trained 16-36 hours per week, and those with history of shoulder or elbow pain.[13] Two studies examined shoulder risk factors for high school athletes with the finding that reduced glenohumeral internal rotation increased the risk for shoulder injury while another found that neither reduced glenohumeral internal rotation or total arc increased the risk for shoulder or elbow pain.[16,18] The same two articles noted that supraspinatus weakness and prone external rotation weakness, respectively, increased the risk. In a study of professional baseball players, strength deficits for both the supraspinatus and prone external rotation increased the risk for shoulder and elbow injury.[91] Another study of professional players reported that a loss of shoulder external rotation range of motion increased the risk for shoulder injury.[21]

Agresta et al reported that the factors associated with increased risk for elbow pain included increased age, player position, training 16 to 36 hours per week, and history of elbow pain among youth baseball players between 7 and 11 years old. In a study of youth baseball players between 9 and 14 years old, it was reported that pitching greater than 100 innings per year was significantly associated with elbow injury.[12] In a study of arm injuries among high school baseball players, it was reported that reduced dominant shoulder prone external rotation strength was associated with increased elbow injury risk.[12] In professional baseball players, increased risk for elbow injury was associated with higher peak external rotation shoulder torque and elbow varus at maximum external rotation of the pitching motion, faster pitching velocity, reduced total shoulder rotation deficit, and shoulder flexion deficit.

The risk factors for upper extremity injury among baseball players differed between body region and age group. Youth pitchers were more at risk for shoulder injury based on player position, training time, and history of previous arm injury. High school and professional players were at increased risk for shoulder injury related to reduced pre-season strength and range of motion. Youth players were at more risk for elbow injury if throwing more than 100 innings per year, aged 9-11, being a pitcher or catcher, and training more than 16 hours per week. For professional baseball players, increased risk for elbow injury was associated with elbow varus and shoulder external rotation torque during pitching, passive shoulder rotation and flexion deficits, and high pitch velocity.[12]

It was noted in the discussion by Agresta et al that risk factors for injury have not been studied as extensively as initially thought when narrowing the criteria by excluding research studies that focused on pain instead of injury with lost playing time.[12] Agresta et al noted that studies examining pitching mechanics focused on joint load and fatigue, but there are not any prospective research studies available that looked at the link between certain pitching mechanics and injury.[12] There were also no studies of collegiate players that met the criteria for this systematic review leaving that population without representation. Some of the professional level players are the same age as collegiate level players, but the skill level may have more to do with injury risk than age alone according to the findings of this review. The authors noted that further research is needed to investigate risk factors for injury across all ages and skill levels with clear definition for injury.

Notably, there was a 4-fold increase in the number of elbow surgeries for collegiate baseball pitchers when comparing the time period of 1994-1999 to 2000-2004, and there was also a 6-fold increase for high school baseball pitchers during that same time.[14] This increase warranted a study to identify risk factors that could predispose an adolescent pitcher to a significant shoulder or elbow injury. The participants for this research study by Olsen et al included adolescent baseball pitchers (14-20 years old) who sustained a serious pitching-related injury, which was an injury to the shoulder or elbow of the dominant arm that required surgery.[14] A survey with questions on injury history, playing history, and potential risk factors was given to the injured group and was also sent out to active high school and college pitchers to isolate healthy, age-matched controls. The injured group for this study was comprised of 95 adolescent, male baseball pitchers that had either shoulder or elbow surgery due to a pitching related injury. There were 45 male baseball pitchers utilized for age-matched controls with exclusion criteria including shoulder or elbow pain lasting more than two weeks, shoulder or elbow pain that caused them to miss a game or practice, and recurring shoulder or elbow pain from pitching.[14]

There were three categories chosen for the risk factors of interest: non-modifiable factors, preventive measures, and competition habits. The non-modifiable risk factors chosen were age, height, weight, number of years of pitching, age they began throwing fastball, curveball and change-up, number of years before shaving they began throwing fastball, curveball and change-up, pitcher self-rating and coaches chief concern. The preventive measures included whether or not they received private pitching instruction, were involved in an exercise program, exercise with free weights, exercise with tubing for the rotator cuff, exercise that included aerobic activity, exercise designed for pitchers, stretch before pitching, stretch after pitching, number of warm-up pitches, regular use of NSAIDs, regular use of ice and regular use of topical analgesics. The competition habits included in the survey were months per year of competitive pitching, number of pitching appearances per year, number of innings per appearance, number of pitches per appearance, number of pitches per year, number of fastball, curveball and change-ups thrown out of 10 pitches, how often are they a starting pitcher, if they regularly stayed in the game at another position after pitching, how often returned to the mound in the same game, how often a relief pitcher, how often they started another position before relieving, how often they pitched with arm fatigue, if they continue to pitch despite arm pain, fastball speed, and number of career showcases participated in. The variables chosen in this study were based on previous literature and proposed risk factors.[14]

The results of this study from Olsen et al reported that age for the injured group (18.6 ± 1.6) and control group (18.3 ± 1.5) were similar; number of years of pitching was also similar at 9.2 ± 2.6 for the injured group and 9.0 ± 2.4 for the control group.[14] The injured group was significantly taller (185.0 ± 6.6 cm) and heavier (86.0 ± 11.0 kg) compared to the control group (181.3 ± 5.4 cm and 80.6 ± 10.1 kg, respectively). The injured group pitched significantly more months during the year (7.9 ± 2.5) than the control group (5.5 ± 2.3), more games per year at 28.8 ± 14.7 compared to 18.6 ± 13.0, more innings per game at 5.6 ± 1.4 compared to 4.3 ± 1.7, and more pitches per game at 87.8 ± 21.8 compared to 66.2 ± 25.3. The injured group was also more likely to be a starting pitcher and pitched in more showcases (events intended to measure ability specific to baseball similar to a football combine). The injured group pitched with higher velocity and more frequently with arm pain and fatigue. The injured group also used non-steroidal anti-inflammatory drugs (NSAIDs) and ice more frequently than the control group. The risk factors listed previously with significant differences between the injured group and control group were the same for both the elbow and shoulder.[14]

Olsen et al also analyzed the data to determine the most significant risk factors and identified four variables through a multivariate logistic regression.[14] The model revealed that injury risk increased 5-fold for pitching more than 8 months out of the year and 4-fold for pitching more than 80 pitches per game. Pitching a fastball speed more than 85 mph increased injury risk 2.58 times and pitching often despite arm fatigue increased the risk of injury 36 times. The primary surgical procedure for the elbow performed on the injury group was ulnar collateral ligament reconstruction (53 surgical procedures), loose body removal and osteophyte excision (4 surgical procedures each), ulnar nerve transposition (3 surgical procedures), ORIF for medial epicondyle fracture (1 surgical procedure), and radial head plica excision (1 surgical procedure). The primary surgical procedure for the shoulder on the injured group was labrum repair (29 surgical procedures), capsulorrhaphy (3 surgical procedures), rotator cuff debridement (2 surgical procedures), Bennett lesion excision (1 surgical procedure), glenoid debridement (1 surgical procedure), and subacromial decompression (1 surgical procedure). All of these surgical procedures were determined to be needed due to pitching-related injuries.

From this research article, high school- and college-age pitchers at increased risk for injury were taller and heavier with suggestion from the author that these pitchers were able to throw harder.[14] The injured and control group were age matched, so they were not able to make inferences about increased risk related to age. Olsen et al also noted that there was not a significant relationship between throwing breaking pitches and injury risk. The injured group threw significantly more months out of the year, games per year, pitches per game, and pitches per year with suggestion by the authors that reduction of injury risk could be achieved through a reduction of any one of these variables. As noted in previous research,[10,12,13] this study also reported that pitching with arm fatigue was an increased risk for injury as well as throwing with higher velocity. A potential cause of pitching-related injuries identified by several researchers is the pitchers that throw harder are more likely to be utilized as they are more successful. Also, it may be the combination of increased velocity with a tendency for coaches to have those pitchers throw more often that leads to increased risk for injury.[14]

Overall, risk factors for arm injuries among baseball pitchers include age, height, throwing breaking pitches, pre-season supraspinatus weakness, high pitch velocity, throwing in showcases and limited glenohumeral internal rotation.[10-19] Of the many proposed risk factors, fatigue is perhaps the most significant. Youth pitchers that reported throwing with arm fatigue were at 36:1 increased risk for shoulder or elbow injury. Playing baseball year-round, playing on multiple teams, playing multiple positions and specialization of training can lead to overuse and fatigue. Previous research on risk factors for arm injuries among baseball pitchers has focused on youth, collegiate, and professional level pitchers with less attention to high school pitchers. There has also been a lack of research toward internal risk factors such as shoulder range of motion restriction, shoulder instability, and throwing biomechanics. Therefore, the work for this dissertation focused on shoulder range of motion and throwing biomechanics as risk factors for throwing-related shoulder pain in high school baseball pitchers.

SHOULDER RANGE OF MOTION CHANGES AND INJURY AMONG BASEBALL PITCHERS

The issue of arm injuries among baseball players has been investigated extensively over the past 20 years with consensus that throwing-related arm injuries to the shoulder among baseball pitchers has the highest injury incidence.[1-7] One of the risk factors identified has been shoulder range of motion adaptations with two primary concepts emerging: TA and GIRD. The term GIRD has remained consistent throughout the reported research, but the TA concept has also been referred to as total range of motion (TROM) or total range of motion for the dominant shoulder (TRD). The concept of TA came with the discovery that shoulder range of motion adaptation is common in throwers whereby glenohumeral external rotation increases and glenohumeral internal rotation decreases on the dominant shoulder in the 90/90 position (90º abduction and 90º elbow flexion) causing a shift of the TA in the direction of external rotation. A shift that is nearly equal in the amount of external rotation gained and internal rotation lost may not be at increased risk for injury, but researchers have reported increased risk with a greater than ± 5º difference when compared to the non-dominant shoulder.[23] GIRD refers to the amount of glenohumeral rotation in the 90/90 position that is lost when comparing the dominant to non-dominant shoulder.

According to a research study by Bullock et al, upper extremity injuries among baseball players continues to be a significant and persistent problem with injury rates increasing at all ages and skill levels of the sport.[20] The relationship between shoulder range of motion and arm injury among baseball players was investigated through systematic review and meta-analysis. The purpose of this study was to critically assess the methodological quality and level of evidence in the literature that investigated the relationship between shoulder ROM and the risk of upper extremity injuries among baseball players. A total of 707 studies were identified for initial review and eventually six studies with n = 1056 participants were found to meet criteria and were included for analysis. The six research studies reviewed were all prospective with quality scores on the modified Downs and Black scale ranging from 11 to 14 out of 15. All six studies had a comparison group and compared throwing to non-throwing arms. Three out of six of the articles analyzed shoulder ROM as a continuous variable, one as ordinal groups and the other two as a nominal risk factor with a cutoff point. All six of the researchers measured glenohumeral internal rotation, external rotation and total range of motion; three researchers also measured horizontal adduction and two researchers measured shoulder flexion.[20]

The results of the meta-analysis by Bullock et al revealed that internal rotation, total range of motion and horizontal adduction were significant predictors of upper extremity injuries among baseball players.[20] The overall pooled assessment for absolute shoulder internal rotation deficit was a predictor of injury (p < .001, -5.93º). The shoulder internal rotation range of motion pooled bilateral deficit was a predictor of injury (p = .02, 4.28º). Three of the studies included for internal rotation deficit defined injury as greater than seven days missed baseball activities while one study defined injury as one missed game or practice. There were 437 participants for the four reported studies finding a significant relationship with internal rotation deficit and injury, and all four of these studies identified the participants as high school aged players ranging from 13 to 19 years old. There were 592 participants in two studies for professional and minor league players (20 – 29 years old) included for the overall pooled assessment for absolute total range of motion, and it was found to be a significant predictor of injury (p = .003, - 6.19º). The overall pooled assessment for absolute shoulder horizontal adduction was a predictor of injury (p < .001, - 8.32º), and the studies included were the same as previously mentioned for internal rotation. Shoulder range of motion that was not found to be significant for injury was absolute shoulder external rotation and bilateral total range of motion. Bullock et al concluded from this systematic review and meta-analysis that absolute shoulder internal rotation and total range of motion less than 44º and 160º and side-to-side deficits in excess of 5º and 8º, respectively, should be considered when designing upper-extremity injury prevention programs. The more commonly reported side-to-side internal rotation deficit is far different from the 15º or 18º cutoff previously reported by Burkhart et al.[23] The authors also reported that absolute internal rotation less than 44º and side-to-side internal rotation deficit greater than 5º indicated the greatest risk for arm injury. This finding is also different from one of the early reports of injury risk related to shoulder range of motion that placed more emphasis on side-to-side differences for total range of motion.[20]

Studies on the relationship between shoulder range of motion and injury among baseball pitchers have reported cutoff points for GIRD between 5º and 18º, and cutoff points for TA between 5º and 8º.[23,24] A specific cutoff point has not been agreed upon with a range of values reported to be at increased risk for injury. Researchers have noted that the range of values for both GIRD and TA that are associated with injury is likely due to a multitude of other factors known to be related to shoulder injury among baseball pitchers such as pitch counts, rotator cuff strength, biomechanics, etc.[20] To date, research for the relationship between shoulder range of motion and injury among baseball pitchers has performed measurements and then tracked injury that occurred at a later date. There has not been a study that measured GIRD and TA for baseball pitchers reporting current throwing-related shoulder pain. This dissertation focused on a specific population that reported current throwing-related shoulder pain that did not keep them from participating but limited the amount of throwing they were able to perform.

SHOULDER RANGE OF MOTION ADAPTATION AMONG ASYMPTOMATIC BASEBALL PITCHERS

There is consensus amongst research studies for baseball pitchers that shoulder range of motion changes occur that shift the osteokinematics in the direction of shoulder external rotation when measured in the functional throwing position or 90/90 position (90º shoulder abduction, 90º elbow flexion) whereby there is an increase in external rotation and a decrease in internal rotation.[31-34] The amount of shift for asymptomatic baseball pitchers varies considerably with ranges from a few degrees to 40º+ compared to the normal of 90º external rotation and 70º of internal rotation.[20] There has been research attempting to identify the nature of range of motion changes among baseball pitchers. These studies have looked at soft tissue changes, osseous adaptation, joint alignment, and joint laxity.[25,31,32,39,43,44,47] Collectively, shoulder range of motion changes among baseball pitchers is multifactorial and differs from one individual to the next. It is important for those working with baseball pitchers to understand the factors known to cause range of motion changes and how it is assessed.

In a research study by Hurd et al, a profile was reported for glenohumeral internal and external rotation range of motion in uninjured high school baseball pitchers.[31] A total of 210 male, high school baseball pitchers from 14-18 years old participated in this study. The participants could play at multiple positions but the primary position had to be pitcher. The procedures for the study consisted of a 5 to 10 minute warm-up of stretching, jogging, and short-toss followed by shoulder range of motion measurement. The participant was placed supine with the shoulder abducted to 90º and elbow flexed to 90º. A first examiner rotated the shoulder into external rotation until the first cessation of movement or the scapula moved and a second examiner measured with a goniometer. The procedure was repeated for shoulder internal rotation in the 90/90 position and shoulder external rotation at 0º of abduction. The data analysis included side-to-side differences for shoulder internal rotation and external rotation in the 90/90 position, shoulder external rotation at 0º of abduction, and TA.[31]

Side-to-side differences were found in shoulder internal rotation ($t_{209} = 15.304$, $p < .001$) and external rotation ($t_{209} = -13.012$, $p < .001$) in the 90/90 position with internal rotation decreasing an average of 15º and external rotation increasing an average of 10º for the dominant limb when compared to the non-dominant. Age at the time of testing had a small but non-significant impact on shoulder external rotation in the 90/90 position where external rotation increased as age increased. There was not a significant effect of age on internal rotation or total shoulder motion. Also, the number of years of pitching experience and age that participants began pitching did not have a significant influence on shoulder range of motion. The significant differences in shoulder range of motion were similar to other research studies reporting an increase of shoulder external rotation and a decrease of shoulder internal rotation on the dominant arm in the 90/90 position.[32,38,39,43,45,46] It is worth noting in this study design that shoulder range of motion measurements were taken after a warm-up that included “short-toss,” which may have affected shoulder range of motion that would differ from studies that do not include throwing as part of the warm-up. Other research studies have identified acute changes in shoulder range of motion after throwing and given the variability that is uncontrollable when having individuals throw, it is a study design flaw to have only taken measurements after a warm-up that includes throwing.[34,37,39] The author states in discussion that the large sample size has made it possible for the data to provide a profile of glenohumeral rotation motion for uninjured high school baseball pitchers. A limitation of this article may be providing information on shoulder range of motion following a short warm-up that includes light throwing, but should not be considered a profile for clinicians to use as normative data for high school baseball pitchers.[31]

In a research study reported by Wilk et al, passive range of motion characteristics were described for professional baseball pitchers in a literature review and also assessed through study of 369 professional level baseball players over a 6-year period for comparison. This research report was comprehensive for shoulder range of motion values among asymptomatic, professional level baseball pitchers, and it is similar to values reported for other ages and skill levels. Table 1 below is the range of motion values reported for asymptomatic baseball pitchers of various ages and skill levels.

Table 1. Shoulder Range of Motion Values for Baseball Pitchers (Degrees of Joint Motion)

Author	GHER at 90/90 for dominant shoulder	GHIR at 90/90 for dominant shoulder	TRM for dominant shoulder	GHER at 90/90 for non-dominant shoulder	GHIR at 90/90 for non-dominant shoulder	TRM for non-dominant shoulder
Borsa et al	135.5 ± 9.5	59.7 ± 7.0	195.2 ± 12.1	130.4 ± 10.7	68.2 ± 8.6	198.6 ± 26.6
Borsa et al	134.8 ± 10.2	68.6 ± 9.2	203.4 ± 9.7	125.8 ± 8.7	78.3 ± 10.6	204.1 ± 9.7
Chant et al	114 ± 9.8	57.1 ± 8.7	171.1 ± 12.5	104.1 ± 7.4	73.5 ± 9.6	177.6 ± 11.0
Crockett et al	128 ± 9.2	62 ± 7.4	189 ± 12.6	119 ± 7.2	71 ± 9.3	189 ± 12.7
Dwelley et al	Pre-fall: 96.2 ± 12.7	Pre-fall: 45.5 ± 11.1	Pre-fall: 141.7 ± 15	Pre-fall: 92.0 ± 10	Pre-fall: 52.7 ± 11.8	Pre-fall: 144.7 ± 14.4
	Pre-spring: 104 ± 17	Pre-spring: 47.5 ± 8.5	Pre-spring: 151.4 ± 19.9	Pre-spring: 101.7 ± 15.2	Pre-spring: 52.6 ± 10.2	Pre-spring: 145.3 ± 15
	Post-spring: 106.9 ± 19.9	Post-spring: 45.8 ± 10.0	Post-spring: 152.4 ± 19.9	Post-spring: 104.4 ± 17.8	Post-spring: 52.2 ± 11.3	Post-spring: 156.6 ± 17.3
Ellenbecker et al	103.2 ± 9.1	42.2 ± 15.8	145.7 ± 18	94.5 ± 8.1	52.4 ± 16.4	146.9 ± 17.5
Freehill et al	Start of season: 124.8 ± 19.5	Start of season: 70.9 ± 11.8	Start of season: 196.5 ± 22.1	Start of season: 116.3 ± 12.7	Start of season: 76.3 ± 12.4	Start of season: 193.6 ± 19.9
	End of season: 126.3 ± 21.63	End of season: 73.6 ± 13.2	End of season: 199.9 ± 26.0	End of season: 119 ± 16.4	End of season: 81.4 ± 10.4	End of season: 200.4 ± 22.0
Laudner et al	Pretest: 118.6 ± 10.9	Pretest: 43.8 ± 9.5	Pretest: 162.4	N/A	N/A	N/A
	Posttest: 119.2 ± 11.0	Posttest: 46.9 ± 9.8	Posttest: 166.1	N/A	N/A	N/A
Lintner et al	Stretching group: 142.7	Stretching group: 74.3	Stretching group: 216.98	N/A	N/A	N/A
	Non-stretching group: 138.9	Non-stretching group: 55.2	Non-stretching group: 194.2			
Myers et al	121.1 ± 8.7	51.1 ± 14.4	172.2	116 ± 10.3	62.2 ± 13.7	178.2
Osbahr et al	126.8 ± 12	79.3 ± 13.3	203.1	114.5 ± 9.1	91.4 ± 13.6	205.9
Reagan et al	116.3 ± 11.4	43 ± 7.4	159.5 ± 12.4	106.6 ± 11.2	51.2 ± 7.3	157.8 ± 11.5
Wilk et al	136.1 ± 11.2	47.5 ± 10.6	183 ± 14.5	128.6 ± 11	59.1 ± 11	187.7 ± 14.5
Wilk et al	132	52	184	127	63	190

Abbreviations: GHER, glenohumeral external rotation, GHIR, glenohumeral internal rotation, TRM, total range of motion

Based on the findings by Wilk et al, it was suggested that there is a wide range of GIRD values for both asymptomatic and symptomatic baseball pitchers, which could mean that GIRD simply coexists in the two populations and there may be one or many other factors that are the cause for arm injuries among baseball pitchers.[34] There have been multiple definitions and cutoff points for GIRD based on research looking at the relationship of GIRD and arm injury among baseball pitchers. Given the findings reported in this study, the authors also suggested that the variability of GIRD may be due to humeral retroversion. The authors stated that there was not a significant relationship between GIRD and posterior shoulder laxity which is expected given that a tight posterior capsule would restrict posterior glide of the humeral head; also, previous authors have reported that the correlation between GIRD and anterior laxity is common and likely due to the tightening posterior capsule causing alignment of the humeral head to shift anterior and superior on the glenoid.[25,46] However, clinically it seems as if there may be a relationship between posterior capsule tightness and anterior laxity with successful clinical outcome for immediate improvement of GIRD by realigning the humeral head on the glenoid with grade II – IV posterior mobilization of the shoulder. The likelihood that there are multiple factors that could lead to arm injury among baseball pitchers cannot be understated, and this report discussed that likelihood while also stating that the use of GIRD as the sole clinical diagnosis of the disabled shoulder would be speculative at best.[34]

There has been research studying the relationship of GIRD with other factors that could be causing arm injury among baseball pitchers including glenohumeral laxity, glenohumeral stiffness and acromiohumeral distance. Laudner et al sought to determine if a relationship existed between anterior shoulder joint laxity and posterior shoulder tightness (GIRD).[25] Anterior laxity of the shoulder was measured in the 90/90 position with the LigMaster applying from 1 to 12 daN of force, and the distance from first movement to final movement was recorded. Glenohumeral range of motion was measured for horizontal adduction, internal rotation in the 90/90 position and external rotation in the 90/90 position with one investigator positioning the shoulder and moving to the first end feel of the range in each direction while a second investigator measured with a standard bubble goniometer.[25]

The results of the Laudner et al study found a fair relationship between anterior laxity of the glenohumeral joint and shoulder horizontal adduction ROM (r = .53, p = .002) and decreased internal rotation ROM (r = .43, p = .001).[25] There was also a significant difference in the total arc ROM between dominant and non-dominant shoulders. This was the first study to measure joint laxity and ROM with valid and reliable devices that are able to quantify those values (ICC = .84 and SEM = .43 mm for the LigMaster; ICC = .93 and SEM = 1.6º for the Pro 3600 Digital Inclinometer). Laudner et al supports the relationship between glenohumeral anterior laxity, posterior capsule stiffness, increased external rotation, and decreased internal rotation that has been discussed by other researchers.[25,46]

Shoulder range of motion adaptation among baseball pitchers has also been studied for associated changes in alignment of the humeral head. In a research study by Maenhout et al, the acromiohumeral distance was measured in a group of overhead athletes with GIRD. Sixty-two healthy participants between 18 and 30 years old who performed overhead sports activities at least 2 hours per week were taken through measurements for glenohumeral ROM and acromiohumeral distance (AHD). The dominant shoulder of the athletes showed significantly decreased internal rotation (24.7º ± 6.3º, $p \leq .001$), increased external rotation (9.9º ± 8.0º, $p \leq .001$), and decreased horizontal adduction (11.8º ± 7.4º, $p \leq .001$) when compared to the non-dominant shoulder. The dominant shoulder also had significantly smaller AHD at 0º (mean Δ = .4 ± .6 mm, $p \leq .001$), 45º (mean Δ = .5 ± .8 mm, $p \leq .001$), and 60º (mean Δ = .6 ± .7 mm, $p \leq .001$) of shoulder abduction when compared to the non-dominant shoulder. The findings for shoulder ROM are in line with previous research and the hypothesis that there would be smaller AHD was also supported. Previous research for overhead athletes including baseball pitchers has discussed the likelihood of AHD changes,[25,29,30,46] but this is the first study to support that with scientific evidence.[83]

Shoulder range of motion adaptations among baseball pitchers have also been found acutely following a throwing event, days after, over the course of a season, and from one season to the next leading researchers to speculate about the possibility of acute on chronic adaptation. In a study by Reinhold et al, 67 professional baseball pitchers between 22 and 30 years old were taken through measurements of bilateral shoulder ER in the 90/90 position, IR in the 90/90 position, and horizontal adduction.[42] Reinhold et al reported a significant reduction of dominant shoulder IR (-9.5º, $p \leq .001$) and total motion (-10.7º, $p \leq .001$) 30 minutes after pitching that remained present 24 hours after pitching. There was not a difference observed in the non-dominant shoulder.[42] Given the acute response of reduction in shoulder IR ROM, the authors reported that the study supports soft tissue and especially capsular adaptation as a factor for GIRD.[42]

Shoulder ROM adaptations among baseball pitchers have also been studied over the course of a season and from one season to another. In a study of collegiate baseball pitchers, 29 asymptomatic pitchers were taken through shoulder ROM measurements prior to the fall season, prior to the spring season, and after the spring season to determine if any significant changes in shoulder ROM occurred between those times. The results of the study showed similar baseline measurements for shoulder adaptation seen among baseball pitchers with an increase in shoulder ER (96.2º ± 10.0º) and a decrease in shoulder IR (45.5º ± 11.1º) in the 90/90 position. There was not a difference between time measurements for any direction of shoulder ROM.[39] In a study by Freehill et al, 21 asymptomatic major league pitchers were studied from 2004 to 2007 for a total of 29 individual seasons in order to determine if there were changes in shoulder ROM from one season to the next.[45] The results of this study found similar baseline changes in shoulder ROM where there was an increase in ER (124.8º ± 19.5º) and a decrease in IR (70.9º ± 11.8º) in the 90/90 position. There was not a significant change in shoulder ROM in any direction from one season to the next. Previous research has identified and confirmed multiple times that shoulder ROM changes among baseball pitchers is common if not the norm such that shoulder ER increases and shoulder IR decreases.[31,32,34-38] Acute changes immediately after throwing and the next day have also been identified among pitchers confirmed to have the shoulder ROM changes at baseline, but changes over the course of a season and from one season to the next were not found in the above mentioned study. Based on the findings of shoulder ROM changes for these studies, it is possible that asymptomatic baseball pitchers will have a baseline for shoulder ROM that shifts toward increased ER and decreased IR while also displaying acute changes related to the stress of throwing that add to that but return to baseline given enough time.

One of the other causes for range of motion changes among baseball pitchers is an osseous adaptation that has been identified as humeral retroversion. Humeral retroversion is a twisting along the long axis of the humerus in the direction of external rotation. In a study by Tokish et al, the relationship of glenohumeral internal rotation deficit with humeral retroversion was evaluated in 23 major league pitchers.[47] The measurements of interest for this study included shoulder internal and external rotation at 0º of abduction, shoulder internal and external rotation in the 90/90 position and horizontal adduction. Humeral retroversion was measured using the method of Soderlund et al by obtaining a modified axillary view of the dominant and non-dominant arm in the supine position with the shoulder flexed to 90, shoulder abducted 10 and forearm parallel to the long axis of the body.[47] There was also shoulder laxity tests performed for anterior, posterior, and inferior directions by two orthopaedic surgeons that graded the laxity on a 3-point scale: 1. glenoid moves up the fossa but short of glenoid rim, 2. glenoid moves partially over the rim, 3. complete dislocation.[47]

There were no differences between shoulder internal rotation at 0º, shoulder external rotation at 0º or horizontal adduction between dominant and non-dominant shoulders. The dominant shoulder had significantly greater humeral retroversion (11.2º, p = .0008), lesser shoulder internal rotation in the 90/90 position (-18.5º, p = .0006), and greater shoulder external rotation in the 90/90 position (18.7º, p < .0001) when compared to the non-dominant shoulder. The presence of glenohumeral internal rotation deficit was determined for the participants by three separate and defined methods: 1. an internal rotation loss that exceeds the external rotation gain on the dominant arm, 2. a loss of internal rotation with a loss of total arc motion in the pitching arm, 3. a loss of greater than 25º of internal rotation of the pitching arm. A comparison of the GIRD and non-GIRD groups was performed for shoulder range of motion, shoulder laxity and humeral retroversion. The results of that comparison showed a significant average increase of humeral retroversion (15.50° vs. 6.60°, p = .0297), an 18º loss in total arc motion, and a significant increase in anterior shoulder laxity.[47]

Shoulder range of motion adaptation among baseball pitchers of all ages and skill levels has been supported by multiple researchers with a large range of values reported.[31-47] Glenohumeral external rotation in the 90/90 position has been reported to increase anywhere from 10º to more than 40º while glenohumeral internal rotation has been reported to decrease anywhere from 10º to more than 30º when comparing the dominant to non-dominant shoulder. Shoulder range of motion values reported in the literature are well beyond the recommended cutoff point for injury risk for the majority of asymptomatic baseball pitchers further adding to the statement by Bullock et al that shoulder injury is multifactorial.[20] There is also discussion by researchers that the microtrauma that occurs from throwing a baseball causes cumulative structural damage that does not manifest as an injury that prevents participation until reaching collegiate level and beyond.[31,35] Based on this literature review, an appropriate next step for research is a study for shoulder range of motion combined with other factors proposed to increase risk of shoulder injury among high school baseball pitchers.

RELIABILITY AND VALIDITY OF 2D MOTION ANALYSIS

Three-dimensional motion analysis systems are considered the gold standard for evaluating human movement, but they are not ideal for practical use due to cost, space requirement, time needed for testing, and training for operating the system. Two-dimensional motion analysis has been used for decades with multiple software systems available such as Dartfish, Kinovea, and Peak Performance.[48] Advances in technology for high-speed cameras have also made it possible to capture high velocity movements such as those in sports. The use of new technology for 2D motion analysis is evident in many settings including physical therapy clinics, sports training facilities, on the field, and at home. Research studies for the reliability and validity of 2D motion analysis systems have been conducted with current recommendations for use in research and clinical settings.

Michelini et al reported a systematic review in 2019 for the reliability and validity of 2D motion analysis compared to 3D motion analysis for the assessment gait.[48] Thirty studies met criteria for the review with a variety of protocols represented. The majority of the studies assessed parameters during gait in the sagittal plane (22 studies), followed by frontal plane (6 studies), and finally both sagittal and frontal planes (2 studies). The gait parameters represented in the systematic review included flexion/extension angles at the hip, knee and ankle, stance duration, step length, hip adduction angles, gait velocity, trunk angles, and pelvic drop angles.[48] The camera setup in studies varied from 25 cm to 3 m high and 1.27 m to 10 m from the participant with 19 studies using over ground walking and 11 studies using treadmill walking. Camera frequency also varied from 25 Hz to 300 Hz with reports that low frame rate of 25 Hz caused faster movements to be blurred and high frame rate of 300 Hz to blur due to pixilation. All of the studies with the exception of one utilized a motion analysis software to analyze video recordings with the most common software used being Dartfish (n = 5), Kinovea (n = 5), Peak Performance (n = 3), and Siliconcoach (n = 2).[48]

The reliability of 2D motion analysis was reported for intratester, intertester, intrasession, and intersession. Intrarater reliability for pelvic drop angles, gait velocity, and stride time was excellent while sagittal plane hip, knee, and ankle joint angles were poor to excellent. Interrater reliability varied greatly for sagittal plane hip, knee, and ankle joint angles while it was excellent for gait velocity. The intrasession reliability was poor to good for sagittal plane hip, knee, and ankle joint angles, good to excellent for trunk angles, and excellent for stance duration. The intersession reliability for knee flexion/extension angles was fair to excellent. Reliability for all measurements were evaluated based on the software used with a reported range from poor to excellent for Kinovea, good to excellent for Dartfish, and fair to excellent for Siliconcoach. Twelve of the 30 studies in the systematic review by Michelini et al evaluated validity of 2D motion analysis systems by comparing findings with 3D motion analysis.[48] There was moderate to high correlation for knee and ankle joint angles while validity of all other parameters was inconsistent.[48]

Michelini et al reported recommendations for the use of 2D motion analysis based on their systematic review.[48] Based on the current research, 2D motion analysis should be performed with a camera that has a frame rate of at least 50 Hz, a camera that has high definition, and there is adequate lighting.[48] The camera should be set up at a height that is perpendicular to the measurement of interest and the distance may range from one to 10 m. It was also recommended that Dartfish software be utilized due to good to excellent reliability for all gait parameters evaluated. Sagittal plane measurements of hip, knee, and ankle kinematics were more reliable than frontal or transverse plane. Future work toward establishing reliability and validity of 2D motion analysis should focus on developing a standard protocol for the assessment of human biomechanics.[48]

Two-dimensional motion analysis is a popular means for the practical assessment of biomechanics for athletic movements during sports activities. Advances in technology for high-speed and high-resolution cameras have made it more affordable, but there is a need to establish the reliability and validity prior to recommending widespread use.[49] In a systematic review by Lopes et al, the reliability and validity of 2D motion analysis of the trunk and lower extremity during athletic tasks was evaluated.[49] The review included studies evaluating trunk and lower extremity kinematics in the frontal plane for the single-leg squat, unilateral landing, and bilateral landing. The kinematics assessed with 2D motion analysis included frontal plane projection angle (FPPA) of the hip, FPPA of the knee, and lateral trunk motion (LTM).[49]

Lopes et al reported that there was excellent intrarater reliability when utilizing 2D motion analysis to measure hip FPPA, knee FPPA, and LTM during the single-leg squat.[49] There was good to excellent interrater reliability when utilizing 2D motion analysis to measure hip FPPA, knee FPPA, and LTM during the single leg squat. There was moderate to excellent reliability for the same measurements when the same rater measured multiple times on the same day. The intrarater reliability when utilizing 2D motion analysis to measure knee FPPA was moderate to good during the unilateral landing task and good to excellent during the bilateral landing task. There was good to excellent interrater reliability for the bilateral landing task when measuring knee FPPA and excellent interrater reliability for the bilateral landing task when measuring LTM. The intrarater reliability for knee FPPA during unilateral landing tasks when measured on different days was moderate to good and good to excellent for bilateral landing task. The validity of 2D motion analysis compared to 3D motion analysis reported by Lopes et al for the previous athletic tasks was good to excellent for knee FPPA in the frontal plane while all other measurements showed mixed results.[49]

In 2017, Oyama et al published a study on the reliability and validity of quantitative video analysis of baseball pitching motion utilizing 2D video recording.[77] Thirty high school baseball pitchers were evaluated simultaneously with 3D motion capture (Vicon Systems, Centennial, CO) and 2D video recording (Exilim FX-1, Casio Computer Co Ltd. Tokyo, Japan). The 2D video recordings were analyzed for 12 kinematic variables by two researchers utilizing Image J Software (National Institutes of Health, Bethesda, MD). Intrarater reliability was evaluated by having each researcher analyze the video twice at least one week apart. Interrater reliability was evaluated by comparing the analysis between the two researchers. Validity of the 2D angles was estimated with ICC and SEM between the 2D angles and 3D angles.[77] The kinematic variables analyzed were: trunk contralateral flexion angle at foot contact, maximum shoulder external rotation, and ball release; trunk flexion angle at foot contact, maximum shoulder external rotation, and ball release; elbow flexion angle at ball release; shoulder elevation angle at foot contact, maximum shoulder external rotation, and ball release; knee flexion angle at maximum shoulder external rotation and ball release.

Oyama et al reported the intraclass reliability of quantitative video analysis of 2D video recordings of baseball pitching motion as very high with intraclass correlation coefficient around or well above .9 (range: .803-.986) and SEM less than 2.5º.[77] The interrater reliability was also high with ICC above .85 and SEM lower than 3.5º. The only variable with strong validity when 2D motion analysis was compared to 3D motion capture data was trunk contralateral flexion at maximum shoulder external rotation ($ICC_{2,k}$ = .809). The variables with moderate validity when 2D motion analysis was compared to 3D motion capture data included trunk forward flexion at foot contact ($ICC_{2,k}$ = .738), trunk forward flexion at ball release ($ICC_{2,k}$ = .620), shoulder elevation angle at foot contact ($ICC_{2,k}$ = .785), and maximum shoulder external rotation ($ICC_{2,k}$ = .710).

The use of 2D video analysis by coaches, parents, and players is increasing as technology that is available through smartphones, tablets, and smartphone applications has made it readily accessible.[77] The development of applications that allow users to measure 2D angles has also led to some parents and coaches analyzing baseball pitching motion quantitatively.[77] The accuracy of 2D video analysis decreases as the plane of movement moves further from perpendicular with direction of the camera. Still, there are kinematic parameters of baseball pitching motion that may be analyzed quantitatively with 2D video analysis that have high intra and interrater reliability and moderate to strong validity. Oyama et al reported high intra and interrater reliability and moderate validity for maximum shoulder external rotation and trunk flexion.[77] Also, the authors stated that it is feasible to visualize maximum shoulder external rotation and trunk flexion due to the orientation of the trunk at the points when these measurements are taken. Oyama et al discussed trunk flexion angle at ball release and maximum shoulder external rotation may be measured to monitor gross change in pitching which may aid in identifying throwing biomechanics that are associated with increased joint loading of the shoulder.[77]

Two-dimensional motion analysis is utilized in sports medicine and rehabilitation with recent advances in technology making it even more affordable and practical for everyday use.[48,49,77] The reliability of 2D motion analysis is the highest for intrarater when the movement assessed is perpendicular to the field of view (eg, knee flexion in the sagittal plane), the frame rate is 50 Hz or higher, there is good lighting, and the camera is capable of high-definition resolution. The validity of 2D motion analysis when compared to 3D motion analysis is not as well established as the reliability, but researchers have made recommendations based on current evidence. For valid measurement utilizing 2D motion analysis, the movement of interest should be perpendicular to the camera and isolate a single plane (eg, hip adduction in the frontal plane as opposed to hip adduction, internal rotation, and flexion). The validity of 2D motion analysis compared to 3D motion analysis also improved when identifying participants at risk due to larger angles suggesting that as the angles being measured increased they were easier to identify.[49] The recommended guidelines for use of 2D motion analysis based on the current literature were utilized in designing the biomechanical study of throwing mechanics for this dissertation.

BIOMECHANICS OF BASEBALL PITCHING

Throwing a baseball is a complex movement that requires coordination and timing of the entire body to link segments from the lower extremities to the trunk and finally transferring through the arm into release of the baseball.[50,51,53] In the late 1990s and early 2000s, the issue of throwing-related arm injuries was recognized by the sports medicine community with research studies increasing to address the growing problem. Some of the research questions about baseball pitching mechanics included whether or not biomechanics would differ within the same pitcher between trials, between pitchers of different ages and skill levels, and from one body segment to another within and between pitchers. The possibility that throwing biomechanics may differ in these scenarios and that less efficient biomechanics exist has been an area of study for its potential relationship with injury.[50-55]

In a study by Stodden et al, the relationship between fastball velocity and variations in kinematic, kinetic, and temporal parameters was examined within individual pitchers.[53] In this study, 19 healthy, male baseball pitchers between the ages of 18 and 23 years old went through 3D motion analysis for baseball pitching. The participants threw 6-10 maximum effort throws to collect data on 12 kinematic, 11 kinetic, and 11 temporal parameters. The parameters at different points of the pitching delivery included shoulder abduction, horizontal adduction, external rotation, stride leg knee angle, elbow flexion, trunk tilt, pelvis angular velocity, and upper torso angular velocity.[53]

The results of this study reported by Stodden et al were significant for a relationship between fastball pitching velocity and time to maximum shoulder horizontal adduction ($57^o \pm 14^o$, $p < .05$) as well as fastball pitching velocity and time to maximum shoulder internal rotation angular velocity ($104^o \pm 5^o$, $p < .05$).[53] As time to maximum shoulder horizontal adduction increased pitching velocity increased.[53] As time to maximum shoulder internal rotation angular velocity increased pitching velocity increased.[53] Trunk forward tilt at ball release also showed a significant relationship with ball velocity (32 ± 9, $p < .05$) where an increase in velocity was associated with increased trunk forward tilt.[53] Shoulder proximal force and elbow proximal force significantly increased with increased ball velocity with percentage of body weight (BW) values of 118.3 ± 17.8% BW and 100.1 ± 14% BW respectively.[53] Elbow flexion torque also increased significantly 3.6 ± 1.0% BW x height, as ball velocity increased.[53] The authors described the proximal forces acting at the elbow and shoulder being a direct cause from muscle and soft tissue surrounding those joints resisting the large distraction force produced by the arm as it accelerates into ball release. The biggest implication for injury noted by the authors was the dual role of the biceps brachii to slow down elbow extension and resist the distraction force at the shoulder. The potential for increased load on the biceps due to the simultaneous increased load at the elbow and shoulder may be a factor leading to the common SLAP lesion injury seen in baseball pitchers. Peak elbow and shoulder proximal forces have been supported by other researchers as kinetic parameters with the highest amount of force during baseball pitching.[50-52]

In a research study by Escamilla et al, the long-held notion that breaking pitches were more likely to cause arm injuries was evaluated.[55] This study reported that 18 of the 26 kinematic parameters showed significant differences between fastball (FA), change-up (CH), and curveball (CU), and 16 of the 26 kinematic parameters showed significant differences between FA, CH, CU, and slider (SL). At lead foot contact, 3 out of 8 parameters showed significant differences, 4 out of 7 were different during the arm-cocking phase, and all 9 parameters were different for the arm acceleration phase. For the temporal parameters, the only significant difference was in upper torso angular velocity between the CH and CU. Ball velocity was the only parameter that showed a significant difference for all pitch comparisons. The parameters with significant differences included stride length, foot placement, knee flexion angle at foot contact, maximum pelvis angular velocity, maximum upper torso angular velocity, maximum shoulder horizontal adduction, maximum shoulder external rotation, maximum elbow angular velocity, maximum shoulder internal rotation angular velocity, knee flexion at ball release, forward trunk tilt, lateral trunk tilt, elbow flexion angle at ball release, and both hip and knee flexion angle differences at foot contact compared to ball release. The authors noted potential performance implications related to the number of significant differences between pitch types stating that batters may be able to recognize these differences and figure out what pitch will be thrown, which is likely to improve the hitter's performance.[55] Escamilla et al did not discuss any of the differences in kinematic parameters or temporal parameters as it might relate to injury risk.[55]

In a study by Fleisig et al, the difference between pitch types across various levels was evaluated retrospectively in a group of 111 male baseball pitchers at the youth, high school, collegiate, minor league, and major league experience levels.[54] The kinematic and kinetic parameters chosen for this study were similar to the previously mentioned research study by Escamilla et al with the addition of forearm and wrist parameters.[54,55] The results of the study by Fleisig et al found that there were not any differences in any of the kinematic or kinetic parameters between experience levels when normalized for ball velocity.[54] The kinematic parameters that were found to be significantly different ($p < .05$) between pitchers with the same experience level included maximum forearm supination (SEM 2.0º), maximum pelvis rotation velocity (SEM 7 º/s), maximum shoulder internal rotation velocity (SEM 101 º/s), lead knee flexion (SEM 1.2º), trunk forward tilt (SEM .8º), elbow flexion (SEM .7º), and wrist orientation (SEM 2.6º). There were also significant differences for the kinetic parameters between different pitch types but not between experience levels for ball velocity, maximum upper trunk rotation velocity, maximum elbow extension velocity, trunk side tilt at ball release, shoulder abduction at ball release, shoulder proximal force, shoulder internal rotation torque, and elbow varus torque.[54] These were similar findings to previous research,[50-53] and the overall discussion from Fleisig et al is that it does not appear that breaking pitches increase risk for injury, since the kinetics are lower for this pitch across all levels. There was not a significant difference in the pitch types, kinematics, or kinetics between the different levels when adjusted for ball velocity suggesting that throwing-related arm injuries is less related to age or playing level as it is for other risk factors such as height, weight, velocity, pitch counts, playing multiple positions, and playing on multiple teams.[54]

Additionally, motion analysis has been used to study the timing between various segments of the body during baseball pitching. Multiple articles have reported on the relationship between timing of various kinematic and kinetic variables and how this affects performance and injury.[59-61,70-72] Urbin et al, discussed the importance of efficient mechanics, which was defined as the ability to produce greater output (ball velocity) with less input (ie, joint kinetics).[51] The purpose of this study by Urbin et al was to evaluate the relationship between timing of segmental interactions with ball speed and upper extremity kinetics. The results reported by Urbin et al for timing between temporal segments and how that related to ball speed were significant for increased time from stride-foot contact to peak pelvis angular velocity (.05 m/s) and increased time from peak upper torso angular velocity to peak elbow extension angular velocity (.09 m/s). Decreased shoulder proximal force (1.76 N) was associated with increased time from stride-foot contact to peak pelvis angular velocity and increased time between peak pelvis and upper torso angular velocities. Decreased shoulder internal rotation torque (.14 Nm) and elbow varus torque (.15 Nm) were associated with increased time from stride-foot contact to peak pelvis angular velocity. The timing of peak pelvis angular velocity after stride-foot contact was significantly associated with all other kinetic parameters including elbow and shoulder joint forces implicated in throwing-related injuries.[51] Urbin et al stated that these findings indicated that lumbopelvic control is necessary for consistent, efficient mechanics and strength training programs should focus on developing muscles around the hips and core to more effectively time trunk segment and reduce the magnitude of upper extremity kinetics.[51] Additionally, it was identified that there may be a need for optimizing the timing between segments in order to activate the stretch-shortening capability of muscles that produce a summation of speed although the study did not support that directly.[51] Multiple researchers have supported an optimal timing between segments that takes advantage of the stretch-shortening cycle that is part of the development of baseball pitchers and the reason that some are capable of throwing with higher velocity and reducing the risk of injury.[50,53,56,58,59,61,65,67]

Pelvis and trunk rotation have been studied for baseball pitching biomechanics with multiple researchers identifying relationships between pelvis, trunk, and upper extremity kinetics and kinematics.[56,58,59,61,74,75] Aguinaldo et al sought to determine the effect of upper trunk rotation on shoulder joint torque. Forty-eight asymptomatic, male baseball pitchers at the youth (n = 9), high school (n = 12), college (n = 11), and professional (n = 6) level were included in this study. The only significant finding for trunk kinematics was the difference in onset of peak trunk rotation between skill levels with professional level pitchers rotating their torso much later in the pitching cycle (34.3 ± 5%) than college level (14.2 ± 1.5%), high school level (6.4 ± 1.3%), and youth level (5.0 ± .7%).[75] A significant difference between levels was also noted for shoulder internal rotation torque with the professional level (50 ± 9 Nm) being lower than both college (78 ± 9 Nm) and high school (66 ± 6 Nm) levels.[75] Shoulder joint torques have been suggested as a means of identifying baseball pitching biomechanics at greater risk for injury, and Aguinaldo et al supported a more efficient movement pattern in professional level pitchers throwing with greater velocity and lower internal rotation torque.[75]

In a study of pelvis and torso kinematics and their relationship to shoulder kinematics, Oliver et al reported relationships between pelvis and torso kinematics with shoulder elevation angle, shoulder plane of elevation, and shoulder axial rotation at various points of the pitching delivery.[59] The pelvis kinematics of interest were lateral tilt and axial rotation velocity. The torso kinematics of interest were flexion, lateral tilt, and axial rotation velocity. Shoulder elevation at foot contact had a strong inverse relationship with axial rotation velocity at both the pelvis (r = -.719) and torso (r = -.734).[59] Shoulder elevation at maximum shoulder external rotation also had a strong relationship with axial rotation velocity at both the pelvis (r = -.653) and torso (r = -.720).[59] The authors discussed the likelihood that hyperangulation of the shoulder, identified by previous researchers[59,60,71] to be at risk for injury, is related to early and rapid trunk rotation supported by this study. The need for training programs for baseball pitchers that includes strength and stability of the core muscles including gluteal musculature is supported by the findings of Oliver et al.[59]

Another relationship of interest for baseball pitching biomechanics has been the association between kinematics and kinetics of the hip with the upper extremity. In a study by Holt et al, 31 healthy youth baseball pitchers between 9 and 11 years old were taken through passive hip range of motion measurements and 3D motion analysis to determine if any significant relationships existed between the hip and upper extremity.[56] There was a significant correlation between dynamic stance hip rotation and scapular upward rotation (r - .531, p = .002) at the point of maximum shoulder external rotation and ball release, but no other significant relationships between dynamic hip motion and upper extremity motion or dynamic and passive hip motion were reported.[56] Based on the study findings, Holt et al recommended that youth pitchers need to focus on lower extremity flexibility, especially at the hip.[56] There was not a significant correlation between passive hip range of motion and dynamic hip range of motion, so Holt et al recommended dynamic instead of passive testing and training for hip range of motion, although no specific movements or exercises were suggested.

There are kinematics and kinetics occurring at the shoulder joint during baseball pitching that have been hypothesized to be associated with throwing-related shoulder pain.[69-73,75,76] Kinematics of the shoulder during baseball pitching that may be at increased risk for injury include shoulder horizontal abduction; kinetics of the shoulder during baseball pitching that may be at increased risk for injury are peak proximal force and peak anterior force. Keeley et al looked at peak shoulder anterior force and peak shoulder proximal force in a group of 19 healthy, youth baseball pitchers between 9 and 13 years old.[67] There was not a significant relationship between peak shoulder anterior force and shoulder pain, but there was a significant relationship between peak shoulder proximal force and shoulder pain. Peak shoulder proximal force was a significant predictor of shoulder pain and for every 1N increase of force there was a 4.6% increase in the likelihood of the pitcher reporting shoulder pain.[67] Keeley et al discussed the possibility that increased peak shoulder proximal force may cause shear stress on the glenoid labrum with resultant microtrauma and pain.[67] Additionally, training for torso control and scapular positioning during baseball pitching are important injury prevention strategies that have been shown by other researchers to be related to changes in peak shoulder proximal force.[59,67]

The relationship of shoulder horizontal abduction with shoulder joint load was studied by Takagi et al.[66] Due to the large amount of shoulder external rotation during the cocking phase of throwing, it is likely that anterior translation of the humeral head occurs and any additional shoulder horizontal abduction from the point of maximum shoulder external rotation into arm acceleration could be at increased risk for injury.[66] The results of the study by Takagi et al supported the hypothesis that there would be a correlation between horizontal abduction/adduction angle and anterior/posterior shear force at maximum shoulder external rotation. A larger horizontal abduction force was associated with greater anterior shear force.[66] The increase in anterior shear force at the shoulder due to large shoulder external rotation range of motion along with horizontal abduction torque has been reported by multiple researchers as a potential injury mechanism during baseball pitching.[66-73] Anterior shoulder laxity has been implicated for shoulder labrum injury, anterior instability, rotator cuff injury, and internal impingement.[66-

[73] According to Takagi et al, training for baseball pitching biomechanics should include management of shoulder horizontal abduction as a means to reduce harmful stresses at the shoulder.[66]

There are several kinetic and kinematic parameters for baseball pitching biomechanics that are supported by research to reduce joint load with discussion by those researchers that biomechanics that reduce stress while maintaining ball velocity are more efficient and reduce the risk for injury.[66-76] Only one study to date has defined a group of correct baseball pitching biomechanics and evaluated their relationship to parameters supported by previous research to be at increased risk for injury.[66,71,73] Davis et al studied 169 asymptomatic baseball pitchers from 9 to 18 years old using a 3D motion analysis system and evaluated five biomechanical parameters: leading with the hips, hand-on-top position, arm in throwing position, closed-shoulder position, and stride foot toward home plate.[70] Leading with the hips required that the pelvis lead the trunk toward home plate through the early cocking phase. Hand-on-top position was correct if the forearm remained in pronation as the throwing hand was separated from the glove during the early cocking phase. The arm in throwing position was correct if the shoulder was abducted to its highest point by stride foot contact. The closed-shoulder position was correct if the lead shoulder remained closed and pointed toward home plate at stride foot contact. The stride foot toward home plate was correct if the stride foot pointed toward home plate at stride foot contact.[70] The parameters were scored and compared to humeral internal rotation torque (HIRT) and elbow valgus load (EVL), which previous researchers have discussed in relation to shoulder and elbow injuries.[66-76]

Davis et al reported that correct performance of the 5 biomechanical parameters was significantly associated with reduced HIRT and EVL.[70] The pitchers that performed 3 or 4 out of 5 of the parameters correctly had lower HIRT and EVL compared to the pitchers that performed 1 or 2 of the parameters correctly.[70] Davis et al also noted that older pitchers (ages 14-18) performed significantly better on the 5 parameters than youth pitchers (ages 9-13) suggesting that more experience may improve pitching performance. Two things that were found in this study that were unexpected was that leading with the hips increased both HIRT and EVL, and the suggestion was made that generating more velocity may be accomplished by leading with the hips and greater force will be generated at the shoulder and elbow as a result.[70] The other unexpected finding was that youth pitchers performed the stride foot toward home plate parameter correctly more often than adolescent pitchers.[70] Davis et al discussed the fact that increased kinetics cannot be proven to increase the risk for injury, but it is currently accepted as a means to draw conclusions with regards to injury.[70] The biomechanical parameters chosen by this researcher as correct may not be the correct mechanics, but the comparison and how each affected forces about the shoulder and elbow is useful information for those working with baseball pitchers.

Previous research has looked at the variation between pitches, pitchers, and a multitude of biomechanical parameters, although data for nearly all of these studies is collected in a single motion analysis session for the individual pitcher.[50-67] One of the few studies to date with follow-up testing was conducted by Fleisig et al as a 7-year study of pitching biomechanics changes within individuals.[68] Fleisig et al reported significant changes in several kinetic parameters: maximum elbow varus torque, normalized elbow varus torque, maximum shoulder internal rotation torque, normalized shoulder internal rotation torque, maximum shoulder horizontal adduction torque, normalized shoulder horizontal adduction torque, maximum elbow flexion torque, normalized elbow flexion torque, maximum shoulder proximal force, normalized shoulder proximal force with $p < .01$ for all.[68] There were also changes in positional parameters including longer stride, closed foot position, and more trunk separation. Fleisig et al discussed the greatest increase in elbow varus torque was seen from 13-15 years old with possible association to the high rate of ulnar collateral ligament (UCL) tears seen for baseball pitchers 15 years and older. It was also noted that kinematic parameters changed the most in the first few years of pitching with inferences by the author that ages 9-13 years old appeared to be the time when changes in pitching biomechanics for position was the most significant.[68] Given the complex nature of throwing a baseball, which is similar to other sports movements such as the tennis serve, there is a lot of time and practice that must be dedicated to develop the most efficient pattern. It makes sense that there would be a lot of change, and hopefully improvement, in the first few years of pitching that eventually levels off with only small changes seen after a certain age.[68]

Baseball pitching biomechanics have been studied extensively with a few key concepts that guided the biomechanical study of this dissertation work. Kinetic and kinematic parameters during baseball pitching showed significant differences for ball velocity and pitch type, so this dissertation controlled for any differences in biomechanics by measuring ball velocity and using fastball only. One of the kinetic parameters identified by multiple researchers to show differences in their study and also have implications for injury risk was trunk rotation timing. Trunk rotation timing relative to foot contact and timing of other segments was found to differ between skill levels and also for participants reporting shoulder pain. Two kinematic parameters identified by researchers to show differences for ball velocity, pitch type, timing with other segments, joint loads, and pain were shoulder external rotation and trunk forward tilt. Based on the current literature for baseball pitching biomechanics, this dissertation focused on trunk rotation timing, maximum shoulder external rotation, and trunk flexion as parameters that are implicated for injury risk and are supported by research utilizing 3D motion analysis. These parameters were also chosen based on the guidelines of research for reliability and validity of 2D motion analysis.

TREATMENT FOR GIRD

Research studies evaluating treatment for the correction of GIRD have focused on various stretching protocols that differ by type of stretch, technique, frequency, and duration of treatment.[80-85] In a study of 61 collegiate baseball pitchers 19-20 years old, Laudner et al compared an experimental group performing the sleeper stretch to a control group that did no treatment for improvement of GIRD.[25] The sleeper stretch was performed in sidelying, shoulder abducted to 90º, elbow flexed to 90º, and the scapula stabilized by weight of the body pressing it against the table. The shoulder was then internally rotated by using pressure from the hand of the non-dominant arm until a good stretch was felt on the posterior aspect of the shoulder.[25] The stretch was performed three times with 30 second holds in the stretch position. Pre- and post-treatment measurements were taken after a single stretching session performed passively with the assistance of a physical therapist. The experimental group performing the sleeper stretch had a mean improvement of 3.1º for shoulder IR compared to .4º for the control group.[25] In clinical treatment, a warm-up prior to stretch along with additional exercises is often used to make even greater gains for shoulder IR during a physical therapy treatment session. In this study there was no warm-up or additional exercises that may have improved the amount of shoulder IR beyond what was reported.

In a study by Sauers et al, the Fauls routine (see Table 2) was evaluated for acute gains in shoulder mobility including internal rotation.[85] The participants were 30 male, collegiate baseball pitchers from 19 to 21 years old. The stretching routine was performed on the dominant arm only and compared to the non-dominant arm for a control group. Each of the stretches was performed in a single session by a physical therapist for 10 sets of 7 second holds until a comfortable stretch was reported by the participant. The experimental group showed a mean increase of shoulder internal rotation of 6.4° compared to 1.5° for the control group, $p < .05$.[85] There was a greater increase of shoulder internal rotation for this study compared to the Laudner study, which was also a study of a single treatment session change in shoulder range of motion. It is unknown from the Sauers study which of the stretches/exercises produced the gain of shoulder internal rotation since there were several, but for clinicians there is evidence that acute gains may be made with the Fauls routine.

Table 2. The Fauls Modified Passive Shoulder Stretching Routine

Position	Stretching Routine
Sidelying	1. Shoulder Roll Clinician rotates athlete's entire shoulder complex. 2. Pectoral Stretch The athlete's arm is taken into full flexion and the clinician then simultaneously pulls the scapula toward him/herself while also pushing the arm over the athlete's head. 3. Extension Stretch Athlete's arm is taken into full extension. 4. Flexion Stretch Athlete's arm is taken into full flexion. 5. Shoulder Circles Arm in 90° abduction and 90°elbow flexion, clinician gently rotates athlete's glenohumeral joint.
Supine	6. The Pump Stretch Clinician's forearm under proximal humerus and the shoulder is taken into extreme horizontal abduction. 7. Shoulder Flexion Stretch Athlete's arm is taken into full flexion. 8. Internal Rotation Stretch Arm in a position of 90° abduction and 90°elbow flexion, the athlete's arm is taken into internal rotation. 9. External Rotation Stretch Arm in a position of 90° abduction and 90°elbow flexion, the athlete's arm is taken into external rotation. 10. Elbow Circles The clinician supports the athlete's elbow and gently rotates it in large circles, both directions. 11. Wrist Circles The clinician supports the athlete's wrist and gently rotates it in large circles, both directions. 12. Arm Waves The clinician holds the athlete's hand in both hands and vigorously waves the entire arm up and down.

Reprinted from: Sauers E, August A, Synder A. Fauls stretching routine produces acute gains in throwing shoulder mobility in collegiate baseball players. *J Sports Rehabil*. 2007;16:28-40.

In a study of 15 male, collegiate baseball pitchers from 19-21 years old, Oyama et al investigated the effectiveness of a cross-arm stretch, sleeper stretch at 90º, and sleeper stretch at 45º during a single treatment session.[84] The cross-arm stretch was performed in standing with the shoulder blade stabilized against a wall, shoulder flexed to 90º, and the arm pulled across the body into horizontal adduction until a comfortable stretch was felt by the participant. The sleeper stretch was performed in sidelying with the shoulder abducted to 90º and the elbow flexed to 90º while pressure was maintained to hold the scapula in place. The shoulder was then internally rotated by using pressure from the hand of the non-dominant arm until a good stretch was felt on the posterior aspect of the shoulder. An additional sleeper stretch was also performed at 45º of abduction compared to the usual 90º.[84] Three sets of 30 second holds were all performed as self-stretches by the participant. Pre- and post-measurements for shoulder internal rotation were analyzed for mean differences. The cross-arm, sleeper at 90, and sleeper at 45 improved a mean of

4.4º, 3.8º, and 4.6º, respectively ($p < .001$).[84] This is another example of significant improvement in shoulder internal rotation range of motion during a single treatment session for baseball pitchers with GIRD.

In addition to previously discussed research studies that evaluated the acute effects of a shoulder stretch for correction of GIRD, there have been studies investigating the effect of a stretching program over a longer period of time.[83,86] In a study by McClure et al, participants in baseball, tennis, volleyball, and swimming from 19 to 24 years old with GIRD greater than 10º were compared to a control group for both the sleeper stretch and the cross-body stretch.[86] The sleeper stretch was performed in sidelying with the shoulder abducted to 90º and the elbow flexed to 90º while pressure was maintained to hold the scapula in place. The shoulder was then internally rotated by using pressure from the hand of the non-dominant arm until a good stretch was felt on the posterior aspect of the shoulder. The cross-body stretch was performed in standing, shoulder flexed to 90º, and the arm horizontally adducted by using the hand of the non-dominant arm placed on the posterior distal humerus until a good stretch was felt on the posterior shoulder. For this study the stretches were passive and self-performed daily with 5 sets of 30 second holds for 4 weeks.[86] The sleeper stretch group improved 12.4º, the cross-body group improved 20º, and both experimental groups were significant for change in shoulder internal rotation when compared to the control group.[86]

In a study by Maenhout et al, GIRD along with ACH distance was evaluated before and after a 6-week stretching program.[83] The participants in the study were 62, healthy overhead athletes recruited from recreational sports associations that included volleyball, tennis, water polo, squash, and badminton. The athletes were included if they had GIRD greater than 15º and excluded if they had a history of shoulder pain in the past 6 months or history of shoulder surgery. The participants were divided into an experimental (n = 32) and control group (n = 30). Initial measurements of shoulder range of motion and sonographic images of the subacromial space were obtained.[83] The experimental group performed a daily sleeper stretch (similar manner as described previously) on the dominant shoulder for 3 sets of 30 second holds following instruction by a physical therapist and a home program that included written instructions and images for the stretch. The results of the study reported a significant increase of internal rotation (13.5 ± 8º), horizontal adduction (10.6 ± .9º), and acromiohumeral distance (.5 ± .06 mm) for the dominant arm of the experimental group.[83] There were not any significant changes in shoulder range of motion or acromiohumeral distance for the non-dominant shoulder of the experimental group or either shoulder for the control group.[83] This was the first study to evaluate the sleeper stretch in isolation over a period of time rather than before and after the stretch. The gain of internal rotation was greater than those reported in the single stretch sessions suggesting that there is a cumulative effect of the stretch that is achievable with multiple sessions. Notably, the research studies by McClure et al and Maenhout et al evaluated the effectiveness of various stretches for overhead athletes over time but neither of those two studies were specific to baseball pitchers.[83,86]

In a study by Alrdridge et al, 28 healthy, collegiate baseball pitchers from 18 to 21 years old participated in a 12-week stretching program for the posterior capsule to determine the effectiveness for treatment of GIRD.[80] The standard set for GIRD in this study required all three of the following: 1. a 20º deficit of dominant arm shoulder internal rotation compared to the non-dominant, 2. a 20% difference for the same measure, and 3. a 10% difference for total range of motion.[80] Only 10 of the 28 participants met the criteria, although all of the athletes exhibited less shoulder internal rotation on the dominant arm compared to the non-dominant.[80] The stretching program was performed daily during practice or before competition under the supervision of athletic trainers and consisted of 6 variations of the sleeper stretch: 1. prone, 2. prone with assist, 3. sidelying at 90°, 4. sidelying at 45°, 5. sidelying above shoulder level, and 6. supine internal stretch by an athletic trainer. Each of the stretches was performed 3-5 times with 30 second holds.[80]

Aldridge et al reported a significant improvement (p = .04) of GIRD from pre-stretching (48.89º ± 8.46º) to post-stretching (54.07º ± 13.85º) following a 12-week stretching program.[80] The amount of shoulder internal rotation gained over 12 weeks was less than reported in research for other overhead athletes over a 4- and 6-week period, which is likely due to the fact that the study was performed during the fall training/competition phase. During training and competition that involves throwing, it is likely that the posterior capsule is being stressed with subsequent tightening. Still, the fact that a significant improvement was seen during that time is promising for stretching programs that may be used during the season to not only prevent GIRD, but also show improvement for some. The pre- and post-stretching values for GIRD have a large standard deviation, so it is difficult to know how the stretching program may affect shoulder range of motion for each individual. The increase of mean shoulder internal rotation range of motion over the 12-week stretching program was approximately 6º, which some have reported in a single stretching session. Based on the results of this study, recommendations can be made that a stretching program during a competitive season may be used to prevent GIRD and make small, but significant improvements in shoulder internal rotation.

In a study by Lintner et al, a group of 81 asymptomatic baseball pitchers were observed for differences in shoulder IR between 42 of the pitchers that had been performing a stretching program for greater than 3 years and 39 of the pitchers that had been performing the same program for less than 3 years.[87] The Houston Astros stretching program that was utilized consisted of the sleeper stretch and horizontal adduction stretch with 5 variations although that detail was not stated in the article. The stretches were self-guided, assisted by a physical therapist, and also active. The group that had been performing the stretching program greater than 3 years had a shoulder internal rotation measurement mean of 74.3º while the group performing the stretching program less than three years had a mean shoulder IR of 55.2º, which showed a significant difference ($p < .01$).[87] There were not pre- and post-measurements reported which was a design flaw since the purpose of the study was to determine the impact of an internal rotation stretching program on GIRD, which was not accomplished in what was reported. The results of this study give a comparison of the 2 groups, but an assumption must be made that the group stretching greater than three years had greater internal rotation due to the additional time on the program and not for another reason such as starting with greater shoulder internal rotation than the group stretching less than 3 years.

Treatment for glenohumeral internal rotation deficit among baseball pitchers has been shown to be effective following a single session as well as multiple sessions anywhere from 2 to 12 weeks.[80-87]

Effective treatments supported by research include the sleeper stretch, cross-body stretch, and Fauls Shoulder Passive Range of Motion Program. Further research is needed to determine if the improvement is maintained and the number of days or perhaps weeks that it takes to produce the desired gains in shoulder internal rotation. There is also further study necessary to determine if single-session improvements in GIRD reduce risk of injury. Further research is also needed to determine how the range of motion is changing over a longer period time and not just before and after a single session or a few weeks of stretching. This information could be used to make recommendations for appropriate length of time for a stretching program to improve GIRD and maintain shoulder internal rotation range of motion.

TRAINING BASEBALL PITCHING BIOMECHANICS

The Texas Baseball Ranch holds an annual seminar called "The Ultimate Pitching Coaches Bootcamp" (UPCBC) where dozens of experts from all different backgrounds with expertise working with baseball pitchers discuss various aspects of training.[89] The training for baseball pitching biomechanics that is reviewed here is directly from UPCBC, and includes the drills that were used in the research studies for this dissertation. The primary training technique used by this author in assessment and treatment of baseball throwing-related injuries is backward chaining, which was first introduced at the UPCBC in 2003. Backward chaining refers to breaking the pitching delivery into steps starting with follow through and working back to the beginning of the delivery.

The backward chaining baseball pitching drills described by Ron Wolforth of the Texas Baseball Ranch are the final arc, isolated trunk rotation, and lunge torque.[89] The final arc begins in the position of ball release, which looks like a full lunge with the throwing arm extended out as though the ball was just about to leave the hand. The pitcher then leans back bringing the baseball toward maximum shoulder external rotation, immediately moves forward to the starting position, and throws the baseball. This drill may be performed with the back foot on a chair or the ground and may allow release of the back leg or keep it in the original position. The purpose of the final arc is to isolate the finish and follow through of the pitching delivery. The isolated trunk rotation drill begins in a position with the pitcher facing the opposite direction from the stretch position (right-handed pitcher toward 1st base instead of 3rd base) with feet around shoulder width apart, the trunk is rotated toward throwing arm side into maximum shoulder external rotation, and then rotated forward into release of the baseball and follow through. The purpose of the isolated trunk rotation drill is to increase hip and shoulder separation and decrease trunk rotation timing. The lunge torque drill begins in the lunge position with hand held out at the point of ball release followed by a large weight shift onto the back leg with trunk rotation toward maximum shoulder external rotation and then an immediate forward movement into the throw. The purpose of the lunge torque drill is to improve use of the lower extremities, hip and shoulder separation, and trunk rotation timing. Each of the backward chaining drills builds off the other toward the full pitching delivery.[89]

There has been one study to date that has investigated the ability of baseball pitchers to improve biomechanics following a biomechanical evaluation. Fleisig et al evaluated the biomechanics of 46 baseball pitchers from the high school level through professional level utilizing 3D motion analysis.[88] Instructions were given to the pitchers for correction of up to 8 biomechanical parameters if the athlete was more than one standard deviation above or below values for those parameters measured on 100 elite level pitchers.[88] The parameters of interest were chosen based on proposed injury risk in previous research[66-76] and included shoulder and elbow angles at initial lead foot contact, front foot landing position, maximum knee height, peak pelvis angular velocity, peak upper trunk angular velocity, timing between the previous two parameters, and knee extension at ball release. The pitchers were given a detailed video analysis with corrections to make and were able to contact the American Sports Medicine Institute throughout the study to better understand the findings and discuss solutions. The participants returned for follow up evaluation between 2 and 24 months after initial testing. The participants did not show significant changes in height, mass, or ball velocity. There were 138 flaws for the 46 participants on initial testing, and 61 of those (44%) were corrected on final testing. There were 223 parameters within normal range on initial testing with 41 of those (18%) found to be outside of normative range on final testing.[88] Fleisig et al reported that it was a “mixed bag of success” for correction of biomechanical flaws due to less than half of the flaws corrected, and new flaws existing at follow-up. There were two parameters at ball release, knee extension and shoulder abduction, that had the least number of corrections, which was likely due to difficulty with changing flaws at the end of the kinetic chain.[88] Still, there has been a previous report of baseball pitching biomechanics with significant differences over a 7-year follow up and due to over half of the parameters in this study changing, it is possible for baseball pitching biomechanics to change. Further study of these changes and how to influence them toward injury prevention will be important.

Training for baseball pitching biomechanics is available through private instruction, seminars, online videos, and books, but there is a lack of peer reviewed literature to support it. Although the training drills utilized at the Texas Baseball Ranch and in this dissertation are based off of research for biomechanics and sports training, the best practices for training baseball pitchers is purely anecdotal. The study by Fleisig et al supported that certain biomechanical parameters of baseball pitching can be changed through training, but the specifics of the training were not reported.[88] Further research is needed to determine how specific throwing drills affect biomechanics both short and long term, whether or not joint load and torque may be reduced through training of biomechanics, and if injury risk may be reduced.

SUMMARY

This comprehensive review of the literature found a need to explore three questions: 1. is there a difference in shoulder range of motion between high school baseball pitchers with and without the presence of throwing-related shoulder pain?, 2. is there a difference in throwing biomechanics between high school baseball pitchers with and without the presence of throwing-related shoulder pain?, and 3. is there a treatment protocol that is effective for correction of GIRD, improvement of throwing biomechanics, and reduction of shoulder pain level among high school baseball pitchers with throwing-related shoulder pain?

CHAPTER III

COMPARISON OF SHOULDER RANGE OF MOTION IN HIGH SCHOOL BASEBALL PITCHERS WITH AND WITHOUT THE PRESENCE OF THROWING-RELATED SHOULDER PAIN

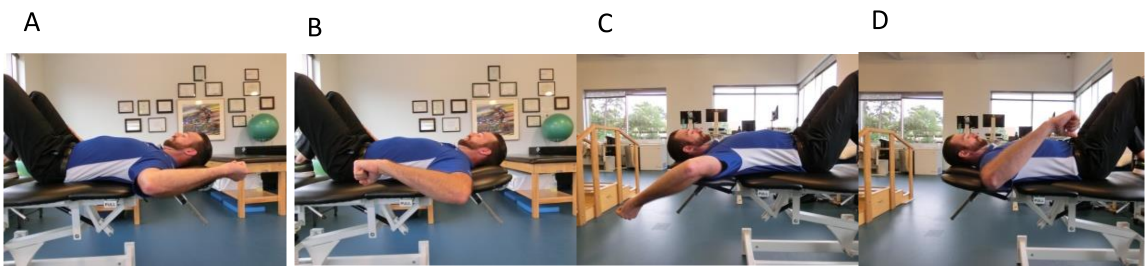
INTRODUCTION

High school athletes often experience added pressure in hopes of earning a college scholarship or professional contract. High school baseball pitchers are being challenged to throw more and perform at their best during a time when many have not reached full musculoskeletal maturity.[1] Throwing-related shoulder injury among high school baseball pitchers has not gone unnoticed; yet there is more literature for college and professional level pitchers. There is anecdotal evidence that high school baseball pitchers may continue to throw with shoulder pain, but the majority of them do not develop an injury that keeps them from participating until reaching college or professional level baseball. In 2004 and 2007, USA Baseball Medical and Safety Advisory Committee revised the rules on pitch counts for youth and adolescent baseball pitchers stating that excessive pitching causes pain, and those that continue to throw with pain are at increased risk for a serious injury.[5] Unfortunately, by the time the injury is recognized it is often too late to intervene without surgical intervention, and there is no guarantee of a full recovery and full return to competition. In order to make a significant impact on throwing-related shoulder injuries baseball pitchers at the high school level should be assessed to identify developing problems before significant structural damage occurs.

There are approximately 5 million participants in baseball aged 6-17 years old with 486 567 participating at the high school level.[1,2] Epidemiological studies of injuries in baseball players of all ages and skill levels have reported the highest injury rate is to the shoulder of pitchers.[1-10] According to a study by Krajnik et al looking at injury rates in baseball and softball from 2005 through 2008 at approximately 74 high schools, the injury rate to the shoulder of baseball pitchers was 1.72 per 10,000 athlete exposures and accounted for 38% of the total reported injuries.[1] Baseball pitchers also accounted for 73% of shoulder injuries requiring surgical intervention. In a 16-year study of injuries in collegiate baseball, 907 throwing-related injuries to the shoulder were reported with 73% occurring in baseball pitchers.[4] The shoulder injuries reported for high school and collegiate baseball pitchers included muscle-tendon strains, incomplete tears, and tendonitis.[1,2,4] Similar shoulder injury rates have been reported for professional baseball pitchers with 28% of all injuries to pitchers occurring at the shoulder joint.[3] The American Sports Medicine Institute in Birmingham, Alabama noted a sharp increase in the early 2000s for surgical procedures of the shoulder in high school and collegiate pitchers due to pitching-related injuries.[6] Shoulder injury incidence rates for all age groups and skill levels of baseball pitchers is an important issue in the sports medicine community with further research needed to develop strategies to reduce and prevent injury.

Shoulder range of motion adaptation in baseball pitchers has been well documented in the literature with agreement among researchers and clinicians that baseball pitchers gain external rotation and lose internal rotation of the dominant shoulder in the functional throwing position (90° of arm abduction and 90° of elbow flexion; see Figure 8).[11-19] The measurements in previous research and this report are for passive shoulder range of motion, so all references of shoulder range of motion are for passive movement. Research into the relationship between shoulder range of motion and shoulder injury among baseball pitchers has led to the development of two major concepts: GIRD and TA. GIRD is the difference between dominant and non-dominant shoulder internal rotation measured in the functional throwing position. TA is the addition of shoulder external and internal rotation in the functional throwing position comparing dominant and non-dominant shoulders. Research studies in professional baseball pitchers have reported a range of acceptable cutoff points for GIRD between 13° and 18° while the acceptable cutoff for TA difference is 5°.[15,19] In a study of 11 collegiate baseball players, participants with pathologic internal shoulder impingement demonstrated an average loss of 19.7° of internal rotation while a group of matched controls demonstrated an average loss of 11.1°.[16] In a study by Hurd et al, 210 asymptomatic high school baseball pitchers were evaluated for shoulder external and internal rotation range of motion in the functional throwing position.[13] This study reported an average gain of 10° of shoulder external rotation and an average loss of 15° of shoulder internal rotation. Many of the pitchers in this study exceeded the acceptable cutoff points for both GIRD and TA, but were not experiencing throwing-related arm pain at the time of the study. To date, the relationship between shoulder range of motion and shoulder pain has not been studied in high school baseball pitchers, and it is possible that the acceptable cutoff for TA and GIRD will need to be adjusted for this age group. In addition, no studies have been reported in the literature assessing the relationship of GIRD and TA with shoulder pain in high school baseball pitchers. Further study of the relationship between shoulder range of motion and shoulder pain in high school baseball pitchers is necessary to better understand the development of future problems in this age group.

Figure 8. Positions for Assessment of Shoulder Range of Motion



A Non-dominant shoulder external rotation, B non-dominant shoulder internal rotation, C dominant shoulder external rotation, and D dominant shoulder internal rotation. Note the shift of range of motion toward external rotation on the dominant shoulder of a right-handed pitcher.

Throwing-related shoulder injuries among baseball pitchers of all age groups and skill levels has been a growing concern for the sports medicine community. Much of the research has been specific to collegiate and professional level pitchers while high school level pitchers may possess similar range of motion deficits associated with increased injury risk, but have not developed the structural damage that limits their ability to throw. The findings of this study may be used to help detect changes in shoulder range of motion and make recommendations for injury prevention.

PURPOSE AND HYPOTHESES

The purpose of this study was 1. to determine the relationship between TA and the presence of throwing-related shoulder pain in high school baseball pitchers, 2. to determine the relationship between GIRD and the presence of throwing-related shoulder pain in high school baseball pitchers, and 3. to determine if there was a difference in TA and GIRD between high school baseball pitchers with and without the presence of throwing-related shoulder pain. The hypotheses were 1. There will be a good relationship ($r \geq 0.70$ per Portney and Watkins criteria)[43] between TA and GIRD and the presence or absence of throwing-related shoulder pain, and 2. TA and GIRD would be significantly greater ($p < 0.05$) for high school baseball pitchers with the presence of throwing-related shoulder pain than for those without the presence of throwing-related shoulder pain.

METHODS

Participants

Eighty male high school baseball pitchers from 15 to 18 years old were recruited for this study; forty-two participants (age, 16.52 ± 1.07 years) reporting the presence of throwing-related shoulder pain and thirty-eight participants (age, 16.34 ± 1.13 years) that reported being asymptomatic for at least four weeks prior to data collection for an age-matched control group. The sample size was determined a priori with G*Power 3.1.9.2 using a one-tailed *t*-test, alpha level 0.05, effect size 0.3 and power of 0.80 with recommended sample size of 64. All participants had a primary position of pitcher with at least 2 years of competitive pitching experience. Participants were excluded if they had not been throwing for the previous 4 weeks, had any surgery on the throwing arm that might have altered shoulder range of motion, were receiving treatment on their shoulder, or had shoulder pain at rest just prior to data collection. Participants were also excluded if they had not been throwing within 48 hours of the time of measurement to avoid range of motion changes from lack of throwing. Pitchers with shoulder pain that prevented them from throwing at maximum effort for at least 10 throws were also excluded.

Instrumentation

A standard 12" goniometer with leveling bubble in the stationary arm was utilized for assessing passive shoulder range of motion measurement. The test-retest reliability for measurement with a standard bubble goniometer has an intraclass correlation coefficient from .944 to .990 for both internal rotation and external rotation of the shoulder in the 90/90 position.[14] A questionnaire was given to the participants that included questions for inclusion and exclusion criteria. Three questions were specific to determining the presence of throwing-related shoulder pain: 5. Have you experienced shoulder pain while throwing a baseball within the past week that has limited the amount of throwing you are able to do?, 6. Are you currently experiencing any arm pain?, and 8. Are you currently receiving treatment of any kind for arm pain? For the purpose of this study, throwing-related shoulder pain was a dichotomous variable, either yes or no, to shoulder pain that is limiting throwing but does not keep them from maximum effort of at least 10 throws.

Procedures

The participants were recruited by word of mouth through affiliations of the lead researcher with area high schools and baseball organizations in the Woodlands, TX and surrounding communities. Participants and parents read and signed a consent/assent form approved by Texas Woman's University Institutional Review Board (IRB). A questionnaire was given to determine whether participants met criteria for the study. For the purpose of this study, throwing-related shoulder pain was defined as shoulder pain that originated from and was most intense when throwing a baseball and shoulder pain that limited usual throwing volume but did not keep them from participating. The participants that met criteria for the study were taken through a single session for measurement of dominant and non-dominant shoulder range of motion in a similar manner reported in previous research (see Figure 9).[12,13,19] The measurements were taken at least 2 hours after any sustained activity involving the shoulder and no warm-up was performed prior to measurement. The lead researcher, a physical therapist with 15 years of experience, positioned the participant in supine with the arm in the functional throwing position, stabilized the scapula by holding the coracoid process and spine of the scapula parallel with the table and rotated the shoulder into external rotation until the first capsular end feel was noted. A second researcher, a physical therapist assistant with 10 years of experience, took measurements using a standard bubble goniometer. Three measurements for glenohumeral external rotation were taken and averaged for data analysis. The same procedure was repeated for glenohumeral internal rotation and both measurements were repeated for the other shoulder. The order for shoulder measurements was random and the lead researcher was not aware of which was the dominant vs non-dominant shoulder.

Figure 9. Two-Person Measurement of Shoulder Range of Motion

Measurement for passive glenohumeral internal rotation (picture on the left) and external rotation (picture on the right)

Data Analysis

Data was collected first on paper forms, then entered into an Excel spreadsheet, and finally transferred into SPSS v.25 for data analysis. The Excel spreadsheet was used to calculate GIRD by subtracting the measurement for dominant shoulder internal rotation from the measurement for non-dominant shoulder internal rotation and averaging the result for the three measurements for a final number to be used in SPSS. The Excel spreadsheet was used to calculate TA by adding the measurement for shoulder external and internal rotation of the non-dominant shoulder and subtracting that from the same TA measurement of the dominant shoulder (a positive value represented greater TA range of motion of the dominant shoulder); the three TA values were then averaged for a final number that would be used in SPSS. The presence of throwing-related shoulder pain was a binary variable and entered into SPSS as 0 = without pain and 1 = with pain. The data set was analyzed for outliers, normality, and equal variances to ensure there were no violations of the assumptions needed for statistical analysis. The results of assumption testing specific to outliers in SPSS for a point-biserial correlation revealed one outlier through a box-plot in the group without throwing-related shoulder pain and one outlier in the group with throwing-related shoulder pain. Further analysis with Mahalanobis Distance test revealed that both of these outliers were not influential, and the data points remained in the analysis. A point-biserial correlation was calculated to determine if there was a significant relationship between total arc range of motion and the presence of throwing-related shoulder pain. A second point-biserial correlation was calculated to determine if there was a relationship between glenohumeral internal rotation deficit and the presence of throwing-related shoulder pain. An independent samples *t*-test was then performed to determine if there was a difference in mean total arc between high school baseball pitchers with and without the presence of throwing-related shoulder pain, alpha set at 0.05 for each test. An independent samples *t*-test was then performed to determine if there was a difference in mean glenohumeral internal rotation deficit between high school baseball pitchers with and without the presence of throwing-related shoulder pain, alpha set at 0.05 for each test.

RESULTS

Assumptions for normality and equality of variance were met per Shapiro Wilk's test and Levene's test, respectively. The results of the first point-biserial correlation showed a weak relationship between the presence of throwing-related shoulder pain and TA, which was significant ($r_{pb} = -.213$, $p = .029$). The results of the second point-biserial correlation showed a weak relationship between the presence of throwing-related shoulder pain and GIRD, which was significant ($r_{pb} = -.304$, $p = .003$). The results of assumption testing for an independent samples *t*-test were met for the previous analysis with the addition of the assumption for independence of observations. The results of the first independent samples *t*-test showed there was not a significant difference in TA scores between baseball pitchers with the presence of throwing-related shoulder pain when compared to those without the presence of throwing-related shoulder pain, $t(78) = 1.926$, $p = .058$. This study found that baseball pitchers with the presence of throwing-related shoulder pain had lower TA values ($-2.45 \pm 9.90^{\circ}$) compared to baseball pitchers without the presence of throwing-related shoulder pain ($1.80 \pm 9.84^{\circ}$) although the difference was not significant. The results of the second independent samples *t*-test showed there was a significant difference for GIRD between baseball pitchers with the presence of throwing-related shoulder pain when compared to those without the presence of throwing-related shoulder pain, $t(78) = -2.819$, $p = .006$. This study found that baseball pitchers with the presence of throwing-related shoulder pain had a significant increase of GIRD of 7° ($13 \pm 11^{\circ}$) when compared to baseball pitchers without the presence of throwing-related shoulder pain (6 ± 10º). Figures 10 and 11 provide TA and GIRD values for all participants. Figures 12 and 13 provide mean and standard deviation for TA and GIRD for all participants.

Figure 10. Total Arc Values for All Participants, 42 With and 38 Without the Presence of Throwing-Related Shoulder Pain

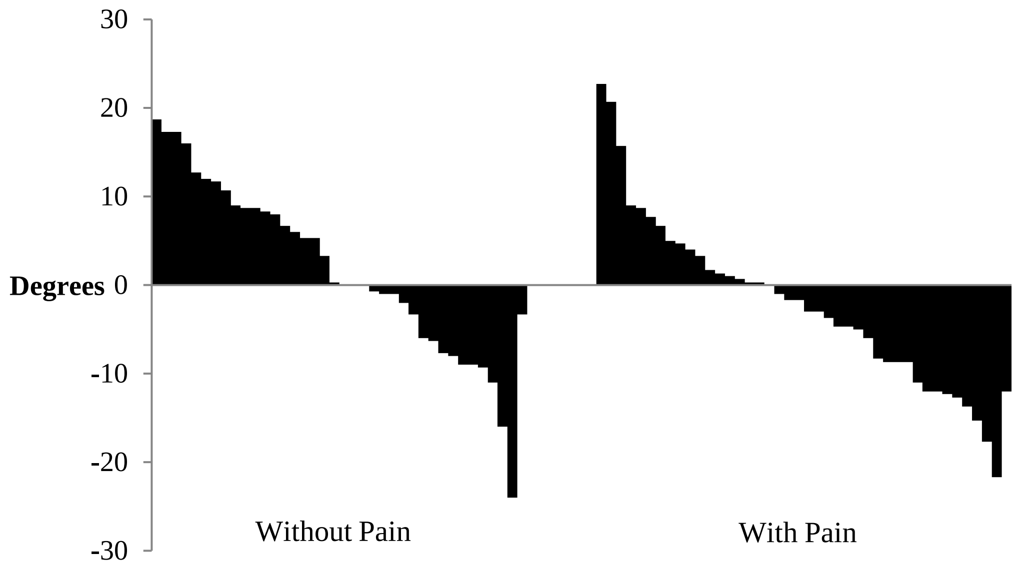


Figure 11. Glenohumeral Internal Rotation Deficit Values for All Participants, 42 With and 38 Without the Presence of Throwing-Related Shoulder Pain

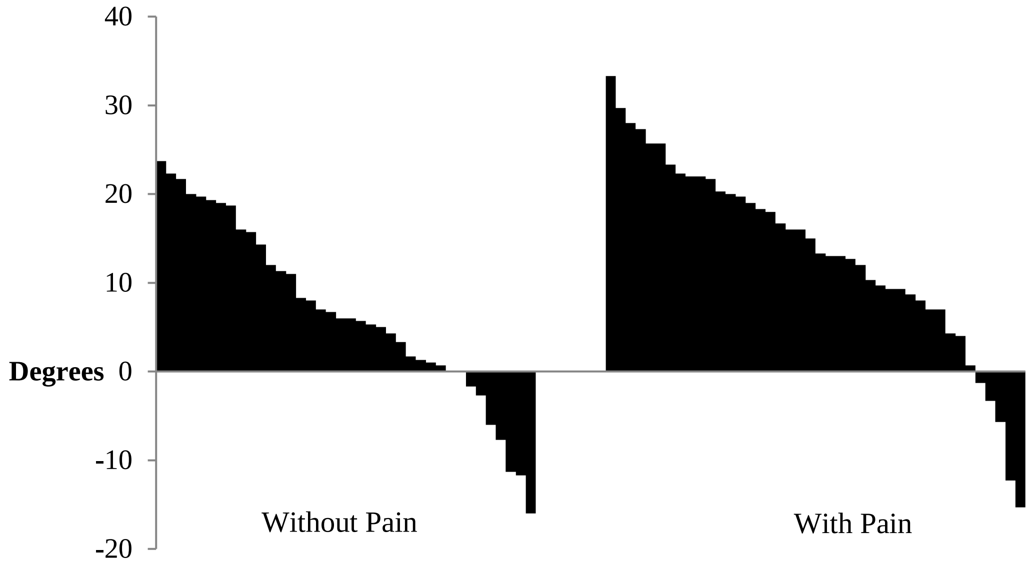


Figure 12. Mean and Standard Deviation for Total Arc

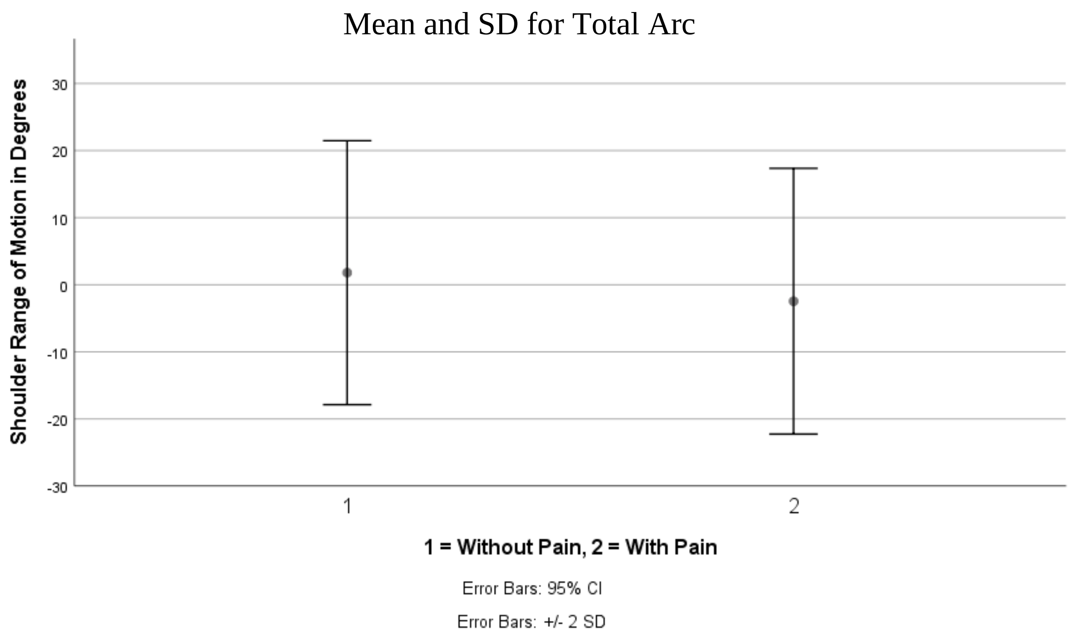
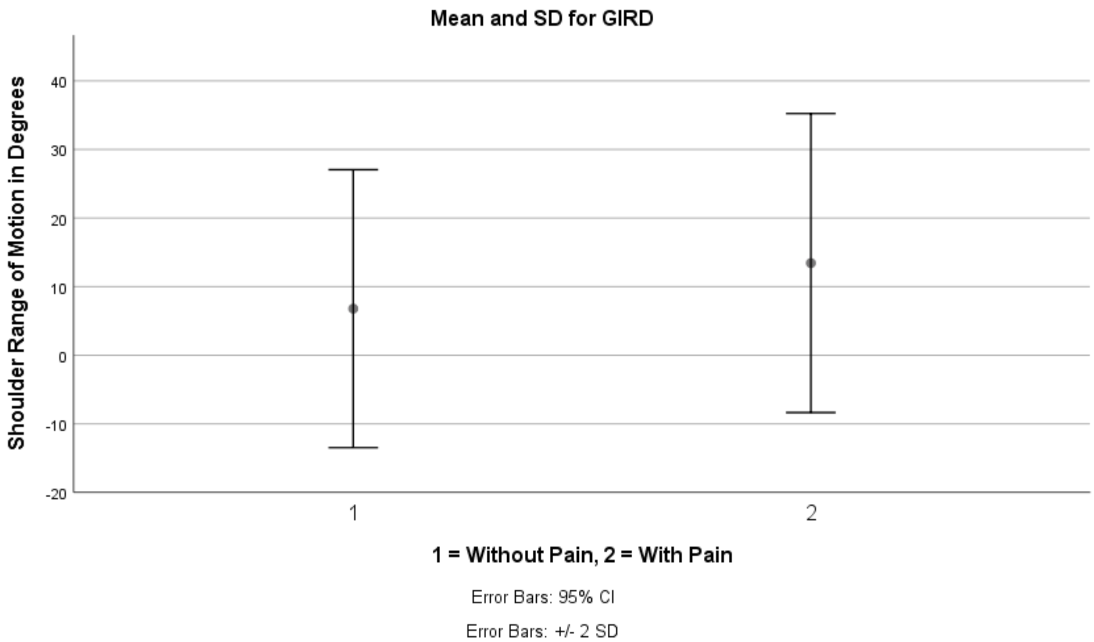


Figure 13. Mean and Standard Deviation for Glenohumeral Internal Rotation Deficit



DISCUSSION

The purpose of this study was to determine if there was a significant difference in TA and GIRD for high school baseball pitchers with and without the presence of throwing-related shoulder pain. To date there has not been a comparison of baseball pitchers reporting the presence of throwing-related shoulder pain at the time of testing to a group of age-matched controls. The results of this study supported the hypothesis that there would be a significant difference in passive shoulder internal rotation range of motion between high school baseball pitchers with and without the presence of throwing-related shoulder pain. Specifically, there was an increase in GIRD on the dominant shoulder of high school baseball pitchers with the presence of throwing-related shoulder pain. In this study, high school baseball pitchers with the presence of throwing-related shoulder pain had on average 7º less shoulder internal rotation than those without the presence of throwing-related shoulder pain. Previous research has shown that GIRD greater than 15º is associated with increased risk for injury.[15,19] The results of this study support that range of motion differences less than the previously recommended cutoff are associated with the presence of throwing-related shoulder pain. It is possible that the high school baseball pitchers with the presence of throwing-related shoulder pain utilized in this study would eventually develop shoulder pain or injury significant enough to prevent them from throwing.

One of the strengths of this study was the use of participants that were able to throw at maximum effort for at least 10 throws but have the presence of throwing-related shoulder pain that limits the total number of usual or expected throws. This population has many of the physical problems related to shoulder pain among baseball pitchers and may be the best way to study and develop prevention strategies for all baseball pitchers. Another strength was the large sample size and power of the study. One limitation of this study is that pain was measured as a dichotomous variable rather than numerically. Further research is needed to follow a group of high school baseball pitchers reporting the presence of throwing-related shoulder pain to determine the percentage of them that eventually develop pain/injury that prevents them from throwing. Further research is also recommended to determine whether or not an increase in GIRD occurs in the time leading to pain/injury that prevents throwing.

RECOMMENDATIONS

High school baseball pitchers reporting the presence of throwing-related shoulder pain should be assessed for GIRD. This study suggests that GIRD greater than 13º in high school baseball pitchers with throwing-related shoulder pain might be appropriate to initiate stretching to improve GIRD, but a recommendation for that is beyond the scope of this study as no treatment was given. It is also possible that monitoring and regular stretching to maintain GIRD less than 7º is appropriate but that too was beyond the scope of this study. Further research is necessary to examine the effect of treatment for correcting GIRD and reducing throwing-related shoulder pain as well as preventative maintenance for shoulder internal rotation to reduce the incidence of throwing-related shoulder pain.

CHAPTER IV

COMPARISON OF PITCHING BIOMECHANICS IN HIGH SCHOOL BASEBALL PITCHERS WITH AND WITHOUT THE PRESENCE OF THROWING-RELATED SHOULDER PAIN

INTRODUCTION

The issue of arm injuries among baseball pitchers is well known in the sports medicine community. In a landmark study by Lyman et al in 2001, the reported incidence of shoulder and elbow injuries among youth baseball pitchers from 9 to 12 years old brought rule changes for youth baseball organizations in an effort to reduce injury. According to multiple researchers, there is still an issue with throwing-related arm injuries and it may, in fact, be worse as the number of baseball organizations and opportunity to participate in games has increased.[1,2,7,8] Research over the past 20 years has increased with attention toward preventing arm injuries. Epidemiological studies for injuries among baseball players have reported the highest incidence of injury is to the shoulder of baseball pitchers.[2-5] Several internal risk factors for shoulder injuries among baseball pitchers have been identified including anthropometrics, age, physical restrictions, and biomechanical problems.[1,7,9,10] Identified external risk factors include high pitch volumes per game, high pitch volumes per season, playing for multiple teams, and playing multiple positions.[1,6,7] The majority of research has focused on youth and professional level baseball pitchers with less attention to high school pitchers. To date the biomechanical research has studied pitchers and then tracked them for the development of pain or injury, but there has not been a study that attempts to identify differences in throwing mechanics when a pitcher reports current throwing-related shoulder pain.

The biomechanics of overhand throwing have been studied with 3D motion capture systems that are able to provide reliable and valid measurements of the kinetics and kinematics of throwing through modeling of the torso and arm with body segment masses.[27,31] Biomechanical research utilizing 3D motion capture has been conducted for asymptomatic baseball pitchers from youth to professional level with an emphasis on understanding throwing mechanics that may lead to injury.[24-34] Some of the throwing parameters studied with 3D motion capture systems include maximum shoulder external rotation, trunk rotation timing, and trunk flexion, which are measured with the anatomically relevant reflective markers. Maximum shoulder external rotation is the greatest degree of shoulder external rotation that occurs in the late cocking phase. Maximum shoulder external rotation has been reported to have a direct positive relationship with anterior force at the glenohumeral joint and has possible implications for injury.[29] Aguinaldo et al reported results from 3D motion capture study and noted that pitchers who demonstrated a later onset of peak trunk rotation timing, which is the instant of the greatest amount of trunk rotation relative to ball release, had greater throwing velocity with less torque on the shoulder and elbow joint.[24] This means that later onset of peak trunk rotation would occur closer to the time of ball release and was reported to reduce stress on the arm. Fleisig et al reported that trunk flexion measured with 3D motion capture system was significantly higher for higher skill levels when comparing youth, high school, collegiate, and professional level pitchers.[38] Trunk flexion has also been identified as a factor with an inverse relationship to joint torques in the upper extremity.[25] Pitchers with less trunk flexion at ball release and during follow through have shown greater glenohumeral joint distraction and internal rotation torques of the upper extremity when throwing biomechanics were evaluated utilizing a 3D motion capture system.[28] Comparison of maximum shoulder external rotation, trunk rotation timing and trunk flexion in high school baseball pitchers with and without throwing-related shoulder pain may identify throwing biomechanics associated with injury risk.

Three-dimensional motion capture is not readily available in clinical practice, but other technologies have been developed that make motion analysis of complex, high-speed movements such as baseball pitching more accessible. Dartfish Pro Suite Video Analysis Software (Dartfish USA, Inc) is among the technologies available for motion analysis of 2D video recording and includes functions for measuring angles and temporal parameters that have been shown to be reliable (ICC = .803-.986).[35,36] Oyama et al evaluated the reliability and validity of 2D quantitative video analysis of the baseball pitching motion and reported that maximum shoulder external rotation and trunk flexion showed high intratester and intertester reliability.[35] Researchers that evaluated the reliability and validity of 2D video analysis recommended using a high-resolution camera with capture rate of at least 50 Hz, measuring joint angles that are perpendicular to the camera view, and measuring temporal parameters.[35,36] Three-dimensional motion capture for baseball pitching mechanics has shown that maximum shoulder external rotation, trunk rotation timing, and trunk flexion are related to increased stress on the shoulder and made inference for injury with further research needed to develop effective treatment and injury prevention strategies. Further research utilizing 2D video analysis to evaluate baseball pitching motion would make a standardized assessment of throwing biomechanics more accessible.

The matter of throwing-related shoulder injury among baseball pitchers of all age groups and skill levels has been a growing concern for the sports medicine community. Researchers have responded with increased study of risk factors proposed to be associated with shoulder injury.[1,6,7,19,27] Much of the research has been specific to collegiate and professional level pitchers. It is hypothesized that high school level pitchers possess many of the problems associated with increased injury risk, but have not developed the structural damage that limits their ability to throw.[10] Identifying throwing biomechanics associated with shoulder pain in high school baseball pitchers may be used to detect mechanical problems earlier and make recommendations for injury prevention.

PURPOSE AND HYPOTHESES

The purpose of this study was to determine if there was a difference in 1. maximum shoulder external rotation during throwing between high school baseball pitchers with and without the presence of throwing-related shoulder pain using 2D video analysis, 2. trunk rotation timing during throwing between high school baseball pitchers with and without the presence of throwing-related shoulder pain using 2D video analysis, and 3. trunk flexion angle at ball release during throwing between high school baseball pitchers with and without the presence of throwing-related shoulder pain using 2D video analysis. The hypotheses for this study were that high school baseball pitchers with the presence of throwing-related shoulder pain would have significantly lower maximum shoulder external rotation values ($p \leq 0.05$), shorter trunk rotation time ($p \leq 0.05$), and lower trunk flexion values ($p \leq 0.05$) when compared to those without the presence of throwing-related shoulder pain.

METHODS

Participants

Seventy-eight male high school baseball pitchers from 15 to 18 years old were recruited for this study; forty-two participants (age, 16.52 ± 1.07 years) that reported the presence of throwing-related shoulder pain and thirty-six (age, 16.34 ± 1.13 years) participants that reported being asymptomatic for at least four weeks prior to data collection for an age-matched control group. The sample size was determined with G*Power 3.1.9.2 using a one-tailed *t*-test, alpha level 0.05, effect size 0.3 and power of 0.80 for a recommended sample size of 71. All participants had a primary position of pitcher with at least 2 years of competitive pitching experience. Participants were excluded if they had not been throwing for the previous 4 weeks, had any surgery on the throwing arm that might have altered shoulder range of motion, were receiving treatment on their shoulder, or had shoulder pain at rest just prior to data collection. Participants were also excluded if they had not been throwing within 48 hours of the time of measurement to avoid range of motion changes from lack of throwing. Pitchers with shoulder pain that prevented them from throwing at maximum effort for at least 10 throws were also excluded.

Instrumentation

A high-speed digital camera (Casio Exilim EX-ZR700, Casio Computer Co, LTD) with capture rate of 480 frames per second was used to video record throwing based on capture rate recommendations from research studies on the reliability and validity of 2D motion analysis. Throwing velocity was measured with Pocket Radar (Santa Rosa, CA). Dartfish Pro Suite Video Analysis Software (Dartfish USA, Inc) was used for motion analysis of video recordings due to the high reliability for measurement of maximum shoulder external rotation, trunk rotation timing, and trunk flexion.[35,36]

Procedures

The participants were recruited by the lead researcher via affiliations with area high schools and baseball academies in the Woodlands, TX and surrounding communities. Participants and parents read and signed a consent/assent form approved by Texas Woman’s University IRB. The participants were allowed a self-guided warm-up to prepare for up to 10 maximum effort throws. A high-speed digital camera was set up on a tripod with 360º level 10 ft from the participant on their throwing side for measurement of maximum shoulder external rotation and trunk rotation timing, and glove side for trunk flexion. The camera position was marked with a cone at the front tripod leg and beginning throwing position was marked with a pitching rubber to ensure consistent set up for data collection. The participants wore their usual baseball practice clothing. Three throws at maximum effort on the throwing side were recorded and then the camera was moved to the glove side where three additional throws were recorded. Throwing velocity was measured for each throw to ensure consistent effort. The video of three throws from each side of the pitcher were then transferred to Dartfish ProSuite Video Analysis software for measurement of maximum shoulder external rotation, trunk rotation timing, and trunk flexion. Video capture and video analysis with Dartfish software were performed by the lead researcher who had training with the software and over 15 years of experience utilizing Dartfish software to analyze baseball pitching motion. In the late cocking phase, maximum shoulder external rotation was measured from neutral to the last point of external rotation prior to the frame of visible transition into internal rotation. The angle was measured with one ray on the x-axis, vertex at the tip of the olecranon, and second ray along the lateral midline of the forearm (see Figure 14). Trunk rotation timing was measured with the time lapse on Dartfish from first foot contact to ball release (see Figure 15). Trunk flexion was measured at ball release as the angle created from the lateral midline of the thigh and lateral midline of the trunk with apex at the visible axis of rotation of the hip joint (see Figure 16). Maximum external rotation, trunk rotation timing, and trunk flexion were chosen for this study because previous research reported high reliability of 2D video analysis for these parameters and studies utilizing 3D motion capture support their relationship with throwing-related shoulder pain .[25,27,28,38] The three measurements for maximum shoulder external rotation, trunk rotation timing, and trunk flexion were averaged for data analysis.

Figure 14. Maximum Shoulder External Rotation Angle in Degrees Measured With Dartfish ProSuite

Figure 15. Trunk Rotation Time Lapse in Dartfish ProSuite

Point of first foot contact (picture on the left) to ball release (picture on the right)

Figure 16. Trunk Flexion Angle Measured in Degrees With Dartfish ProSuite

Data Analysis

The data for maximum shoulder external rotation, trunk rotation timing, and trunk flexion was taken from the Dartfish ProSuite software and recorded in an Excel spreadsheet. The three measurements for maximum shoulder external rotation and trunk flexion were taken directly from Dartfish and averaged in Excel for the final number that would be transferred to SPSS. The measurement for trunk rotation timing consisted of a beginning and ending time in tenths of a second that was transferred to Excel with the difference of the two numbers calculated first and then an average of the three trials providing the final number that was transferred into SPSS 25 Statistical software. Assumption of normality, homogeneity of variance tests and descriptive statistics were run for the data set. A correlation test was run to make sure maximum shoulder external rotation, trunk rotation timing, and trunk flexion were not related and therefore were independent measurements even though they came from the same individual.[47] The three kinematic parameters were not correlated ($r < 0.70$), so three separate independent samples *t*-tests were run to compare each of the three biomechanical parameters between pitchers with and without the presence of throwing-related shoulder pain. The alpha level was divided by three and set at .017.

RESULTS

The results of the first independent samples *t*-test showed that maximum shoulder external rotation for high school baseball pitchers without the presence of throwing-related shoulder pain ($156.5 \pm 10.0^{\circ}$) was not significantly different ($t(76) = 1.285$, $p = .110$) from high school baseball pitchers with the presence of throwing-related shoulder pain ($153.1 \pm 8.3^{\circ}$). The second independent samples *t*-test showed that trunk rotation timing for high school baseball pitchers without the presence of throwing-related shoulder pain ($2.603 \pm .44\ s^{-1}$) was not significantly different ($t(76) = -1.209$, $p = .24$) from high school baseball pitchers with the presence of throwing-related shoulder pain ($2.719 \pm .43\ s^{-1}$). The third independent samples *t*-test showed that trunk flexion for high school baseball pitchers without the presence of throwing-related shoulder pain ($85.5 \pm 12.5^{\circ}$) was not significantly different ($t(76) = .592$, $p = .42$) from high school baseball pitchers with the presence of throwing-related shoulder pain ($83.4 \pm 10.8^{\circ}$). Tables 3, 4, and 5 provide descriptive statistics for maximum external rotation, trunk rotation timing, and trunk flexion, respectively.

Table 3. Descriptive Statistics for Maximum Shoulder External Rotation (in Degrees) for High School Baseball Pitchers Without and With Throwing-Related Shoulder Pain

Maximum External Rotation (degrees)		
Participants Without Pain	Mean	156.45
	Median	156.00
	Variance	100.32
	SD	10.01
	Minimum	132.0
	Maximum	177.7
	Range	45.7
Participants With Pain	Mean	153.10
	Median	154.60
	Variance	68.16
	SD	8.25
	Minimum	132.4
	Maximum	168.8
	Range	36.4

Table 4. Descriptive Statistics for Trunk Rotation Timing (in Time Units) for High School Baseball Pitchers Without and With Throwing-Related Shoulder Pain

Trunk Rotation Timing (seconds^{-1})		
Participants Without Pain	Mean	2.60
	Median	2.55
	Variance	0.19
	SD	0.44
	Minimum	1.8
	Maximum	3.8
	Range	2.0
Participants With Pain	Mean	2.71
	Median	2.60
	Variance	0.18
	SD	0.42
	Minimum	1.9
	Maximum	3.9
	Range	2.0

Table 5. Descriptive Statistics for Trunk Flexion (in Degrees) for High School Baseball Pitchers Without and With Throwing-Related Shoulder Pain

	Trunk Flexion (degrees)	
Participants Without Pain	Mean	85.48
	Median	84.25
	Variance	157.03
	SD	12.53
	Minimum	54.1
	Maximum	111.7
	Range	57.6
Participants With Pain	Mean	83.35
	Median	83.95
	Variance	117.68
	SD	10.84
	Minimum	57.9
	Maximum	114.1
	Range	56.2

DISCUSSION

The purpose of this study was to determine if there was a significant difference between high school baseball pitchers with and without the presence of throwing-related shoulder pain for three biomechanical parameters. This study found that there were no significant differences between the two groups for maximum shoulder external rotation angle, trunk rotation timing from first foot contact to ball release, or trunk flexion angle at ball release. Previous research has found throwing biomechanics related to increased stress on the shoulder including decreased trunk rotation time, less trunk flexion, and less maximum shoulder external rotation.[25,27,28,38] This study did not find a difference for maximum shoulder external rotation, trunk rotation timing, or trunk flexion between high school baseball pitchers with and without the presence of throwing-related shoulder pain, so other risk factors for throwing-related shoulder pain were likely present. It is possible that maximum shoulder external rotation, trunk rotation timing, and trunk flexion have a relationship with throwing-related shoulder pain in other populations of baseball pitchers with further study of these parameters recommended.

This study was the first to look at pitchers reporting the presence of throwing-related shoulder pain to determine if there was a difference in biomechanics when compared to an age-matched control group. Another strength of this study was its inclusion of participants who are able to throw at maximum effort but report the presence of throwing-related shoulder pain that limits them from their usual or expected amount of throwing. High school baseball pitchers with throwing-related shoulder pain that are still able to participate but limited in their usual volume of throwing have many of the physical problems related to shoulder pain among baseball pitchers and may be the best way to study and develop prevention strategies for all baseball pitchers. Also, this study utilized 2D video analysis software that is more accessible as compared to 3D motion capture. However, further study with 2D motion analysis software following guidelines for reliability and validity reported by Oyama et al is recommended.[35] One limitation of this study is the use of 2D motion analysis that is only able to evaluate movement in one plane at a time depending on camera position. Another limitation is that only three biomechanical parameters were studied and other parameters such as stride foot position, knee flexion angle, or shoulder horizontal abduction may have been more valuable for identifying those pitchers at increased risk for throwing-related shoulder pain. Also, this study was a single session, which is another possible limitation since changes in biomechanics from throwing-related shoulder pain may have been evident with additional testing.

RECOMMENDATIONS

Recommendations for training to change maximum shoulder external rotation, trunk rotation timing or trunk flexion cannot be made based on the results of this study, since this study found no differences in maximum shoulder external rotation, trunk rotation timing, or trunk flexion between high school baseball pitchers with and without the presence of throwing-related shoulder pain. Other factors for throwing-related shoulder pain have been reported in the literature and could include physical or biomechanical problems that were beyond the scope of this study.

CHAPTER V

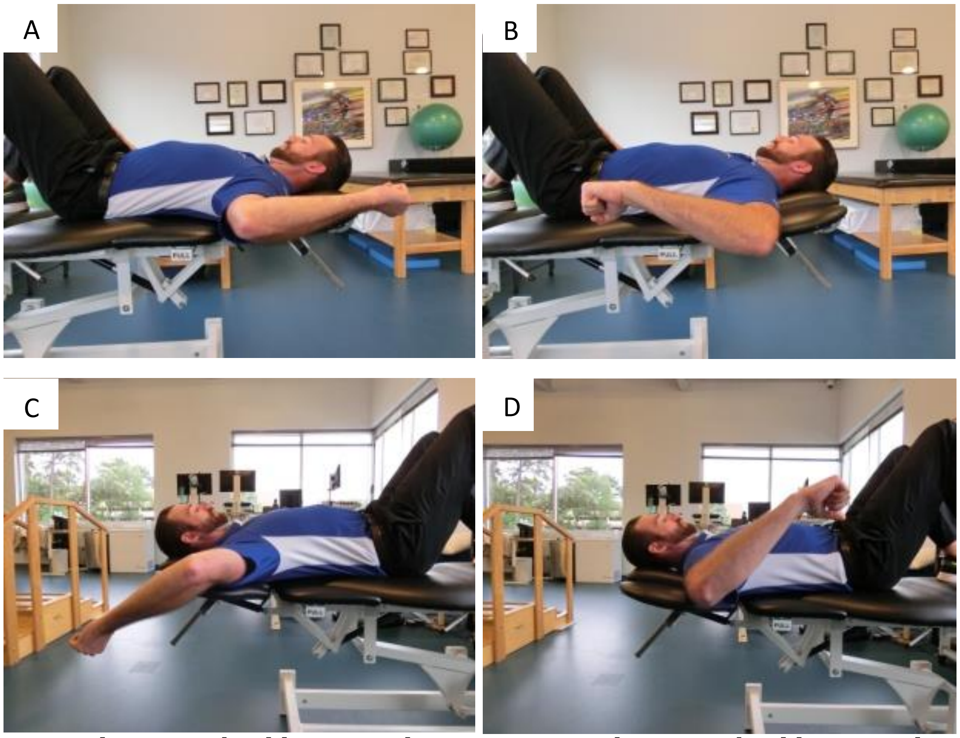
EVALUATION OF FOUR TREATMENT PROTOCOLS FOR CORRECTION OF GIRD, THROWING BIOMECHANICS, AND PAIN LEVEL IN HIGH SCHOOL BASEBALL PITCHERS WITH THROWING-RELATED SHOULDER PAIN

INTRODUCTION

Shoulder injury incidence rates for all age groups and levels of baseball pitchers is an important issue in the sports medicine community with further research needed to develop strategies to reduce injury. Epidemiological studies of injuries in baseball players have reported the highest injury rate is to the shoulder of pitchers.[1-7] Several risk factors have been identified for baseball pitchers and one of the most well-known is the adaptation of shoulder range of motion known as GIRD. Current concepts reported in the literature have discussed appropriate treatment strategies for correction of GIRD in asymptomatic baseball pitchers, but further research is needed to develop treatment strategies for baseball pitchers with GIRD that are experiencing throwing-related shoulder pain.[20,22,23] Research studies specific to the biomechanics of baseball pitchers have identified that there is increased distraction force and internal rotation torque on the shoulder joint with a likely relationship to shoulder pain and injury but study of this relationship to throwing biomechanics and shoulder pain has been speculative at best.[24,25,27,31] Further research is needed to compare treatment protocols for the correction of GIRD as well as explore the relationship between throwing biomechanics and shoulder pain.

Shoulder range of motion adaptation in baseball pitchers has been well documented in the literature with agreement among researchers that it is common for baseball pitchers to gain external rotation and lose internal rotation of the dominant shoulder in the functional throwing position (90° of arm abduction and 90° of elbow flexion, see Figure 17).[11-19] Two major areas of study evaluating the relationship between shoulder range of motion and shoulder injury have been through evaluating GIRD and TA. This study focused on GIRD, which is the difference between dominant and non-dominant passive shoulder internal rotation measured in the functional throwing position.

Figure 17. Positions for Assessment of Shoulder Range of Motion



A Non-dominant shoulder external rotation, B non-dominant shoulder internal rotation, C dominant shoulder external rotation, and D dominant shoulder internal rotation. Note the shift of range of motion toward external rotation on the dominant shoulder of a pitcher.

Research studies in professional baseball pitchers have reported a range of acceptable cutoff points for GIRD between 13° and 18°.[15,19] In a study of 11 collegiate baseball players, participants with pathologic internal shoulder impingement demonstrated an average loss of 19.7° of internal rotation while a group of matched controls demonstrated an average loss of 11.1°.[16] In a study by Hurd et al, 210 asymptomatic high school baseball pitchers were evaluated for passive shoulder external and internal rotation range of motion in the functional throwing position.[13] This study reported an average gain of 10° of shoulder external rotation and an average loss of 15° of shoulder internal rotation. Many of the pitchers in this study exceeded the acceptable cutoff points for GIRD, but they were asymptomatic at the time of the study. To date the relationship between GIRD and shoulder pain has not been studied in high school baseball pitchers, and it is possible that the acceptable cutoff for GIRD should be adjusted for this age group. Further study of the relationship between GIRD and shoulder pain in high school baseball pitchers is needed to better understand potential developing problems in this age group.

Research studies for treatment in the presence of GIRD in throwing athletes have focused on various stretching protocols that isolate the posterior and inferior capsule of the glenohumeral joint.[20-23] In a research study of 28 collegiate baseball players who underwent a 12-week stretching program, internal rotation significantly improved an average of 5° on the dominant shoulder ($p = 0.04$).[20] The stretching program was performed daily and included six different stretches focusing on the posterior and inferior capsule of the shoulder. In a systematic review of six studies for the treatment of persons with GIRD utilizing various stretches for the posterior and inferior shoulder capsule, all of the studies reported significant increases in passive glenohumeral internal rotation.[23] The participants included baseball players, baseball pitchers, and a mixture of athletes and non-athletes between the ages of 18 and 38 years. The results of this systematic review found that a variety of stretches across multiple populations were effective for improving glenohumeral internal rotation. However, no study to date has been conducted for treatment in high school baseball pitchers with GIRD and throwing-related shoulder pain.

The biomechanics of overhand throwing have been studied with 3D motion capture systems that provide reliable and valid measurement for the kinematics of throwing. Biomechanical research utilizing 3D motion analysis has been conducted for asymptomatic baseball pitchers from youth to professional level with emphasis on understanding throwing mechanics that may lead to injury.[24-34] Some of the throwing parameters studied include maximum shoulder external rotation, trunk rotation timing, and trunk flexion. Maximum shoulder external rotation has been reported to have a direct relationship with anterior force at the glenohumeral joint and possible implications for injury.[29] Aguinaldo et al reported that professional level baseball pitchers demonstrated a later onset of peak trunk rotation timing and discussed the likelihood of late trunk rotation reducing stress on the arm.[24] Fleisig et al reported that trunk flexion was significantly larger for higher skill levels when comparing youth, high school, collegiate, and professional level pitchers.[38] Trunk flexion has also been identified as a throwing biomechanics parameter with an inverse relationship to joint torques in the upper extremity.[25] Pitchers with less trunk flexion at ball release and during follow through have shown greater joint torques of the upper extremity. Evaluation of maximum shoulder external rotation, trunk rotation timing, and trunk flexion in high school baseball pitchers with throwing-related shoulder pain may identify throwing biomechanics at risk for injury.

Three-dimensional motion capture is not readily available in clinical practice, but other technologies have been developed that make motion analysis of complex, high-speed movements such as baseball pitching more accessible. Dartfish Pro Suite Video Analysis Software (Dartfish USA, Inc) is among the technologies available for motion analysis of 2D video recording and includes functions for measuring angles and temporal parameters that have been shown to be reliable (ICC = .803-.986).[35,36] Oyama et al evaluated the reliability and validity of 2D quantitative video analysis of the baseball pitching motion and reported that maximum shoulder external rotation and trunk flexion showed high intratester and intertester reliability.[35] Researchers that evaluated the reliability and validity of 2D video analysis recommended using a high-resolution camera with capture rate of at least 50 Hz, measuring joint angles that are perpendicular to the camera view, and measuring temporal parameters.[35,36] Three-dimensional motion capture for baseball pitching mechanics has shown that maximum shoulder external rotation, trunk rotation timing, and trunk flexion are related to increased stress on the shoulder and made inference for injury with further research needed to develop effective treatment and injury prevention strategies. Research utilizing 2D video analysis to evaluate baseball pitching motion would make a standardized assessment of throwing biomechanics more accessible.

The matter of throwing-related shoulder injury among baseball pitchers of all age groups and skill levels has been a growing concern for the sports medicine community. Much of the research has been specific to collegiate and professional level pitchers. It is hypothesized that high school level pitchers possess many of the shoulder range of motion problems and biomechanical flaws associated with increased injury risk but have not developed the structural damage that limits their ability to throw. Research for correction of GIRD and throwing biomechanics among high school baseball pitchers with throwing-related shoulder pain that are still participating may be used to detect problems early and make recommendations for injury prevention.

PURPOSE AND HYPOTHESES

The purpose of this study was to evaluate and compare four treatment protocols for correction of GIRD, improvement of throwing biomechanics, and reduction of shoulder pain level in high school baseball pitchers with throwing-related shoulder pain. The four protocols included self-stretches, manual therapy performed by a physical therapist, manual therapy plus throwing drills, and throwing drills. The hypotheses were 1. There will be a significant difference among the four groups regardless of time on the assessment of GIRD, throwing biomechanics, and shoulder pain level, 2. There will be a significant difference between Time 1 and 2 regardless of group on the assessment of GIRD, throwing biomechanics, and shoulder pain level, and 3. There will be a significant interaction between group and time on the assessment of GIRD, throwing biomechanics, and shoulder pain level.

METHODS

Participants

Forty participants were recruited for this study with thirty-eight participants (age, 16.50 ± 1.05 years) that met criteria and completed data collection; one participant chose to discontinue the study due to increasing shoulder pain of unknown origin that was limiting throwing, and a second participant did not attend a final testing session with multiple attempts to contact. All participants had a primary position of pitcher with at least 2 years of competitive pitching experience. Participants were excluded if they had not been throwing for the previous 4 weeks, had any surgery on the throwing arm that might have altered shoulder range of motion, were receiving treatment on their shoulder, or had shoulder pain at rest just prior to data collection. Participants were also excluded if they had not been throwing within 48 hours of the time of measurement to avoid range of motion changes from lack of throwing. Pitchers with shoulder pain that prevented them from throwing at maximum effort for at least 10 throws were also excluded. A sample size of 32 was determined with G*Power 3.1.9.2 using repeated measures ANOVA within-between, alpha level 0.01, effect size 0.3, and power of 0.80.

Instrumentation

A questionnaire was given to the participants that included questions for inclusion and exclusion criteria. Three questions were specific to determining the presence of throwing-related shoulder pain: 5. Have you experienced shoulder pain while throwing a baseball within the past week that has limited the amount of throwing you are able to do?, 6. Are you currently experiencing any arm pain?, and 8. Are you currently receiving treatment of any kind for arm pain? A 12" standard goniometer with leveling bubble in the stationary arm was utilized for measurement of passive shoulder range of motion. The test-retest reliability for measurement with this type of goniometer has an intraclass correlation coefficient from .944 to .990 for both internal rotation and external rotation of the shoulder in the 90/90 position.[14] For the purpose of this study, throwing-related shoulder pain was rated by the participant on the 10-point numeric pain rating scale, and it was confirmed that pain was limiting throwing but did not keep them from maximum effort of at least 10 throws. A high-speed digital camera (Casio Exilim EX-ZR700, Casio Computer Co, LTD) with capture rate of 480 frames per second was used to video record throwing based on capture rate and recommendations from previous researchers for 2D video analysis. Throwing velocity was measured with Pocket Radar (Santa Rosa, CA). Dartfish Pro Suite Video Analysis Software (Dartfish USA, Inc) was used for motion analysis of video recordings due to the high reliability for measurement of maximum shoulder external rotation, trunk rotation timing, and trunk flexion.[35,36]

Procedures

The participants were recruited by word of mouth through affiliations of the lead researcher with area high schools and baseball organizations in the Woodlands, TX and surrounding communities. Participants and parents read and signed a consent/assent form approved by Texas Woman's University IRB. A questionnaire was used to determine whether participants met criteria for the study. For the purpose of this study, throwing-related shoulder pain was determined as shoulder pain that originated from and is most intense when throwing a baseball and shoulder pain that may limit usual throwing volume but did not keep them from participating. This study included a total of eight sessions; an initial testing session, six treatment sessions, and a final testing session. The initial session was used for measurement of glenohumeral internal rotation similar to that used in previous research[12-14,16,19] with one researcher positioning the shoulder at end range of internal rotation in the 90/90 position while a second researcher measured utilizing a standard bubble goniometer. Participant report of shoulder pain level during or immediately after the most recent throwing session using the 10-point numeric pain rating scale was collected. A video recording of throwing was taken for three throws from the glove side and three throws from the throwing arm side for a total of six video recordings for each participant. There were six treatment sessions lasting 15-20 minutes each over the course of two weeks that were done by the lead researcher who is a board certified orthopaedic clinical specialist, sports therapy certified through the University of St. Augustine, and has over 15 years of experience working with baseball pitchers. A final measurement session one to two days after the last treatment session was performed in the same manner as the initial testing session.

Procedure for initial and final testing session. The participants were told not to warm-up prior to testing so shoulder range of motion could be measured. Passive glenohumeral internal rotation of the dominant arm was measured 3 times and participants were asked to report shoulder pain level during or just after their most recent throwing session. Next, the participants were allowed to go through a self-guided warm-up including throwing to prepare for up to 10 maximum effort throws. Video and velocity were recorded for 3 throws on the throwing side for maximum shoulder external rotation and trunk rotation timing; 3 throws on the glove side for trunk flexion. The camera position was marked with a cone on the front tripod leg and the beginning throwing position was marked with a pitching rubber to ensure consistent set up for data collection. The camera was set on a tripod with 360º level 10 ft from the participant based on manufacturer recommendations. The video recording of 3 throws from each side of the pitcher were transferred to Dartfish ProSuite Video Analysis software for measurement of maximum shoulder external rotation, trunk rotation timing, and trunk flexion. In the late cocking phase, maximum shoulder external rotation was measured from neutral to the last point of external rotation prior to the frame of visible transition into internal rotation with one ray on the x-axis, vertex at the tip of the olecranon, and a second ray through the lateral midline of the forearm (see Figure 18). Trunk rotation timing was measured utilizing the time lapse available through Dartfish software from initial foot contact to ball release (see Figure 19). Trunk forward flexion was measured at ball release and was the angle created from the lateral midline of the thigh and lateral midline of the trunk with apex at the visible axis of rotation of the hip joint (see Figure 20).

Figure 18. Maximum Shoulder External Rotation Angle in Degrees Measured With Dartfish ProSuite

Figure 19. Trunk Rotation Time Lapse in Dartfish ProSuite

Point of first foot contact (picture on the left) to ball release (picture on the right)

Figure 20. Trunk Flexion Angle in Degrees Measured With Dartfish ProSuite

Procedure for treatment session. The participants were placed in one of four treatment groups as follows: participant one went into Group 1, participant two into Group 2, and so on until a sample of N = 10 was reached for each group. See Table 6 for the treatment protocols, Figure 21 for the stretches and mobilization utilized, and Figure 22 for the throwing drills. The types of stretches including three sets of thirty second holds were performed in a similar manner as those reported in previous research studies.[20-23] The 3 throwing drills were specific to the biomechanical parameters being assessed.

Table 6. Treatment Protocols

Protocol	Description
1	Shoulder warm-up with light tubing exercises, supervised self-stretches of three sets of thirty second holds for the sleeper stretch and the horizontal adduction stretch
2	Shoulder warm-up with light tubing exercises, five sets of progressive oscillation manual therapy posterior shoulder mobilizations, stretching by a physical therapist for three sets of thirty second holds for shoulder internal rotation and horizontal adduction
3	Shoulder warm-up with light tubing exercises, five sets of progressive oscillation manual therapy posterior shoulder mobilizations, stretching by a physical therapist for three sets of thirty second holds for shoulder internal rotation and horizontal adduction, ten throws each of the three throwing drills
4	Shoulder warm-up with light tubing exercises, ten throws each of the three throwing drills

Figure 21. Shoulder Stretches and Mobilization

From left to right picturing sleeper stretch, horizontal adduction stretch, manual internal rotation stretch, manual horizontal adduction stretch, manual therapy posterior mobilization

Figure 22. Throwing Drills

From left to right picturing external rotation drill, trunk rotation timing drill, trunk flexion drill for isolation and improvement specific to each biomechanical parameter

Data Analysis

Five variables were analyzed in this study: 1. Passive glenohumeral internal rotation in degrees, 2. Maximum shoulder external rotation in degrees, 3. Trunk rotation timing in seconds, 4. Trunk flexion in degrees, and 5. Pain level. The data was collected during an initial testing session and a final testing session for 38 participants. Three measurements for passive glenohumeral internal rotation of the dominant shoulder from the initial and final testing session were entered into an Excel spreadsheet for calculation of the average of the three values from each session. Three measurements utilizing Dartfish video analysis software for maximum shoulder external rotation, trunk rotation timing, and trunk flexion from the initial and final testing session were entered into an Excel spreadsheet for calculation of the average of the three trials. Pain level during or immediately after the participant's most recent throwing session was reported one time at both the initial testing session and final testing session. The values for each variable were transferred from Excel to SPSS version 25 (IBM Corp.) for data analysis. Assumption of normality, homogeneity of variance tests, sphericity, and descriptive statistics were run for the data set. A split-plot ANOVA was performed for each of the five dependent variables. The alpha level was divided by five for a value of .01 to maintain power.

RESULTS

The assumptions of continuous level dependent variables, related groups for the independent variable and no significant outliers were met. The assumptions of normality and sphericity were also met per Shapiro-Wilk test and Mauchly's test, respectively.

Glenohumeral Internal Rotation

The split-plot ANOVA for the dependent variable of glenohumeral internal rotation was significant for the interaction of time and group ($F(3,34) = 5.315, p = .004$). The simple effects analysis showed significant improvement in glenohumeral internal rotation for each of the four groups. Group 1 performed the self-stretches and improved an average of 16.6º ($p < .001$), Group 2 received manual stretching and shoulder mobilization by a physical therapist and improved an average of 31.7º ($p < .001$), Group 3 received manual stretching and shoulder mobilization by a physical therapist as well as performed three throwing drills and improved an average of 23.6º ($p < .001$), and Group 4 performed only the three throwing drills and improved an average of 13.4º ($p = .001$). Table 7 displays the mean and SD for initial and post-measurements for glenohumeral internal rotation, and Table 8 displays the mean difference for each treatment group from Time 1 to Time 2. The simple effects analysis for differences among groups at Time 1 and Time 2 found a significant mean difference of 14º between Group 1 and Group 2 at Time 1 ($p = .003$) but no additional significant differences were found.

Table 7. Descriptive Statistics for Pre- and Post-Clinical Trial for Glenohumeral Internal Rotation

Glenohumeral Internal Rotation (degrees)					
	IGHIR		PGHIR		
Group	Mean	SD	Mean	SD	N
1	46.33	13.79	62.89	7.85	9
2	32.60	9.47	64.30	5.85	10
3	42.00	6.82	65.60	8.26	10
4	43.22	6.22	56.67	11.48	9

Abbreviations: IGHIR = Initial Glenohumeral Internal Rotation, PGHIR = Post Glenohumeral Internal Rotation

Table 8. Improvement of Glenohumeral Internal Rotation From Initial to Post-Testing for Groups 1-4

Glenohumeral internal rotation difference (degrees)							
Group	Time 1	Time 2	Mean Difference Time 1 to Time 2	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
1	1	2	16.6	3.63	$p \leq .001$	23.926	9.185
2	1	2	31.7	3.44	$p \leq .001$	38.692	24.708
3	1	2	23.6	3.44	$p \leq .001$	30.592	16.608
4	1	2	13.4	3.63	$p = .001$	20.815	6.074

Maximum External Rotation

The results of the split-plot ANOVA for the dependent variable of maximum external rotation were not significant for the interaction of time and group ($F(3,34) = 1.120, p = .355$), the main effect of time ($F(3,34) = .040$, $p = .842$), or the main effect of group ($F(3,34) = .782$, $p = .512$). Descriptive statistics by group can be found in Table 9.

Table 9. Descriptive Statistics for Pre- and Post-Clinical Trial for Maximum Shoulder External Rotation

Maximum External Rotation (degrees)					
IMaxER			PMaxER		
Group	Mean	SD	Mean	SD	N
1	156.06	6.49	153.31	8.70	9
2	150.42	8.47	151.69	7.82	10
3	154.86	6.83	152.71	7.78	10
4	154.22	9.48	156.87	6.25	9

Abbreviations: IMaxER, Initial Maximum External Rotation, PMaxER, Post Maximum External Rotation

Trunk Rotation Timing

The results of the split-plot ANOVA for the dependent variable of trunk rotation timing were not significant for the interaction of time and group ($F(3,34) = 1.482, p = .237$). The results were not significant for the main effect of time ($F(3,34) = 7.099$, $p = .012$), but were significant for the main effect of group ($F(3,34) = 6.220$, $p = .002$). There was a significant difference between Group 1 (M = 3.03 s^{-1}) and Group 3 (M = 2.63 s^{-1}) regardless of time. There was a significant difference between Group 1 (M = 3.03 s^{-1}) and Group 4 (M = 2.38 s^{-1}) regardless of time. Descriptive statistics by group can be found in Table 10.

Table 10. Descriptive Statistics for Pre- and Post-Clinical Trial for Trunk Rotation Timing

Trunk Rotation Timing (s^{-1})					
	ITRT		PTRT		
Group	Mean	SD	Mean	SD	N
1	3.12	.40	2.93	.29	9
2	2.86	.36	2.71	.39	10
3	2.61	.36	2.64	.34	10
4	2.43	.31	2.32	.34	9

Abbreviations: ITRT, Initial Trunk Rotation Timing, PTRT, Post Trunk Rotation Timing

Trunk Flexion

The results of the split-plot ANOVA for the dependent variable of trunk flexion were not significant for the interaction of time and group ($F(3,34) = 2.275$, $p = .097$), the main effect of time ($F(3,34) = .051$, $p = .823$), or the main effect of group ($F(3,34) = 2.562$, $p = .071$). Descriptive statistics by group can be found in Table 11.

Table 11. Descriptive Statistics for Pre- and Post-Clinical Trial for Trunk Flexion

Trunk Flexion (degrees)					
	ITF		PTF		
Group	Mean	SD	Mean	SD	N
1	81.17	9.79	82.04	9.61	9
2	77.46	11.00	79.24	9.45	10
3	87.68	10.57	91.33	10.60	10
4	85.79	9.79	80.61	8.89	9

Abbreviations: ITF, Initial Trunk Flexion, PTF, Post Trunk Flexion

Pain Level

The results of the split-plot ANOVA for the dependent variable of pain level were not significant for the interaction of time and group ($F(3,34) = 3.006$, $p = .044$) or the main effect of group ($F(3,34) = .637$, $p = .597$). There was a significant main effect for time ($F(3,34) = 52.225$, $p < .001$). There was a significant difference for shoulder pain rating from Time 1 (M = 2.58) to Time 2 (M = .98) regardless of group. Descriptive statistics by group can be found in Table 12.

Table 12. Descriptive Statistics for Pre- and Post-Clinical Trial for Pain Level

Pain Level					
	IPainLevel		PPainLevel		
Group	Mean	SD	Mean	SD	N
1	2.8	1.64	.8	1.40	9
2	2.8	1.75	.4	.70	10
3	2.8	1.32	1.5	.97	10
4	1.9	.93	1.2	.97	9

Abbreviations: IPainLevel, Initial Pain Level, PPainLevel, Post Pain Level

DISCUSSION

The purpose of this study was to evaluate and compare 4 treatment protocols for improvement of GIRD, improvement of 3 biomechanical parameters and reduction of shoulder pain level in high school baseball pitchers with throwing-related shoulder pain. The results of the study showed that all 4 treatment protocols showed a significant improvement of passive glenohumeral internal rotaton. The treatment protocol that showed the greatest improvement in glenohumeral internal rotation was Group 2, which was the group that received manual therapy but did not perform any drills specifically targeted to improve any of the three biomechanical parameters. There was a significant main effect of group for trunk rotation timing. This study found differences in trunk rotation timing among high school baseball pitchers, but the results did not support that the throwing drills may have been the reason for this difference. There were no significant findings for the maximum external rotation or trunk flexion biomechanical parameters. There was significant improvement of shoulder pain level from Time 1 to Time 2 regardless of which treatment protocol the participant performed.

The hypothesis for interaction of time and group for the variable glenohumeral internal rotation was met. All four treatment groups showed significant improvement of glenohumeral internal rotation. The hypothesis for the main effect of group was met for trunk rotation timing, but there were no significant findings for the parameters of maximum external rotation or trunk flexion. There was significant main effect of time for the assessment of pain level. All 4 treatment groups demonstrated a significant reduction in shoulder pain level. It is possible that self-stretching, stretching done by a physical therapist, and throwing mechanics drills were the reason for a reduction in pain. It is also possible that improvement in glenohumeral internal rotation was related to a reduction in throwing-related shoulder pain since Group 4 performing only the throwing drills also had a significant improvement of glenohumeral internal rotation. It is possible that the throwing drills improved glenohumeral internal rotation as finish and follow through were part of each of the drills. Previous cutoff in the literature for GIRD has been reported at 15º, and Groups 1-3 improved beyond that amount while Group 4 did not.[10] Based on the results of this study, self-stretching for internal rotation and horizontal adduction may be used to help correct GIRD and reduce throwing-related shoulder pain in high school baseball pitchers. This study also supports the use of manual therapy for internal rotation and horizontal adduction stretching for the correction of GIRD and reduction of throwing-related shoulder pain in high school baseball pitchers. The results of this study did not show that maximum external rotation, trunk rotation timing, or trunk flexion were significantly different following throwing drills performed six times over two weeks. It is possible that a longer period of time is necessary to improve throwing biomechanics supported through previous research to be at increased risk for injury.[24,25,27] This study also supported that the use of throwing drills may improve GIRD and reduce throwing-related shoulder pain.

One of the strengths of this study was the use of four treatment protocols to advance knowledge of best practices for correction of GIRD, improvement of throwing biomechanics, and reduction of shoulder pain level among high school baseball pitchers. Another strength of this study was the use of participants that are able to throw at maximum effort for at least 10 throws, but report the presence of throwing-related shoulder pain that limits them from their usual or expected amount of throwing. This population has many of the physical problems related to shoulder pain among baseball pitchers and may be the best way to study and develop prevention strategies for all baseball pitchers. One of the limitations of this study was the use of 2 weeks for length of time for the treatment protocols as it is possible that fewer days may be as effective and also more time may have shown greater improvement of GIRD, a significant difference in throwing biomechanics, and decreased pain level beyond study findings. Another limitation is that participants were high school age only so generalizability is limited.

RECOMMENDATIONS

Clinicians treating high school baseball pitchers reporting throwing-related shoulder pain who also have an internal rotation deficit should consider either a self-stretching routine or manual stretching. The 3 throwing drills utilized in this study may also be used to increase internal rotation and reduce throwing-related shoulder pain. Also, when throwing drills are performed in conjunction with manual stretching, patients may show greater improvement of internal rotation.

CHAPTER VI

CLINICAL IMPLICATIONS FOR MEASUREMENT OF SHOULDER RANGE OF MOTION, VIDEO ANALYSIS OF PITCHING, AND TREATMENT FOR SHOULDER PAIN IN HIGH SCHOOL BASEBALL PITCHERS

STATEMENT OF THE PROBLEM

Arm injuries among baseball players are common with the highest rate of injury occurring to the shoulder of pitchers. Baseball pitching is a complex, full-body movement that generates excessive joint range of motion and large amounts of torque at the shoulder and elbow. Even with proper training and preparation, injuries may occur and lead to associated medical cost, time lost to participation, and loss of potential college scholarship or professional contract. Shoulder range of motion adaptation including TA and the loss of GIRD as well as inefficient biomechanics are among the risk factors discussed by previous researchers. Research evaluating treatment for GIRD has been limited to single sessions or a 12-week period with further study needed to determine the necessary amount of time needed to make corrections in GIRD and improve shoulder pain among baseball pitchers. In addition, no study to date has utilized video analysis software that is accessible to the public to analyze the biomechanics in high school baseball pitchers with and without throwing-related shoulder pain.

REVIEW OF METHODOLOGY

Study 1

Eighty-two high school baseball pitchers were recruited with eighty of them completing consent forms and data collection; forty-two reporting the presence of throwing-related shoulder pain and thirty-eight reporting being asymptomatic for at least four weeks prior to testing. All 80 participants were taken through measurements for shoulder internal and external rotation of the dominant and non-dominant shoulders. The data was entered into an excel spreadsheet for calculation of GIRD and TA, and those calculations were then transferred to SPSS statistical software v. 25 for data analysis. A point-biserial correlation and independent samples *t*-test were calculated for the comparison between high school baseball pitchers with and without the presence of throwing-related shoulder pain.

Study 2

Forty-two participants from Study 1 that reported the presence of throwing-related shoulder pain, and thirty-six of the participants from Study 1 without the presence of throwing-related shoulder pain also completed Study 2. All of the participants were taken through video analysis of throwing utilizing a digital camera with capture rate of 480 frames per second. Video was captured for 3 throws on the throwing arm side and 3 throws on the glove side while velocity was measured to ensure consistent effort. Dartfish video analysis software was utilized to measure maximum external rotation (degrees), trunk rotation timing (s^{-1}), and trunk flexion (degrees). The data from these measurements was entered into an Excel spreadsheet to average three trials, and then transferred into SPSS statistical software v. 25 for data analysis. Three independent samples *t*-tests were calculated to determine the difference for the three throwing biomechanical parameters between high school baseball pitchers with and without the presence of throwing-related shoulder pain.

Study 3

Thirty-eight of the forty-two participants reporting throwing-related shoulder pain from Studies 1 and 2 completed a two-week clinical study evaluating four treatment protocols for the correction of GIRD, improvement of baseball pitching biomechanics, and reduction of shoulder pain. The results from Studies 1 and 2 were utilized for the initial testing session with the addition of a shoulder pain rating during their most recent throwing session. All of the participants started the clinical trial within 1 week of the initial testing session. The 4 treatment protocols were performed 3 times a week for 2 weeks and the final testing session was completed one to two days after the sixth treatment session. The final testing session consisted of the same shoulder range of motion measurements, video analysis of throwing, and shoulder pain rating that were performed during the initial testing session. The 4 treatment protocols were 1. self-stretching three times for 30 seconds for both the sleeper stretch and cross-body stretch, 2. manual therapy that included 5 sets of progressive oscillation shoulder mobilizations for posterior glide of the humeral head, manual therapy internal rotation stretch 3 times for 30 seconds, and manual therapy cross-body stretch 3 times for 30 seconds, 3. the same as Protocol 2 with the addition of 10 reps of 3 throwing drills that included a drill for maximum external rotation, trunk rotation timing, and trunk flexion, and 4. only the three throwing drills from Protocol 3. The data from the initial and final testing sessions included the shoulder range of motion measurement for GIRD only, the 3 biomechanical parameters, and the shoulder pain rating. This data was entered into an Excel spreadsheet to calculate the average of 3 trials for shoulder range of motion measurements, biomechanical parameter measurements, and calculation of GIRD for the initial and final testing sessions. The data from the excel spreadsheet was entered into SPSS statistical software v. 25 for data analysis. A split-plot ANOVA was calculated for the following 5 variables: 1. Glenohumeral internal rotation, 2. maximum external rotation, 3. trunk rotation timing, 4. trunk flexion, and 5. shoulder pain rating.

SUMMARY OF FINDINGS

There was a weak and significant relationship between shoulder range of motion and the presence of throwing-related shoulder pain among high school baseball pitchers for GIRD. There was also a significant difference for GIRD between high school baseball pitchers with the presence of throwing-related shoulder pain when compared to age-matched norms. The participants that reported the presence of throwing-related shoulder pain had 7° less shoulder internal rotation compared to the participants that did not report the presence of throwing-related shoulder pain. There was not a significant difference for each of the three baseball pitching biomechanical parameters evaluated between high school baseball pitchers with the presence of throwing-related shoulder pain and those without. There was significant improvement of GIRD for all four treatment protocols: 1. self-stretching, 2. shoulder mobilizations and manual stretching by a physical therapist, 3. shoulder mobilizations and manual stretching by a physical therapist as well as throwing drills, and 4. throwing drills only. There were no significant differences found for maximum shoulder external rotation, trunk rotation timing, or trunk flexion. There was a significant reduction in pain level from initial testing to final testing regardless of treatment group.

CLINICAL RELEVANCE

Physical therapists working in outpatient and especially sports medicine facilities are likely to treat high school baseball pitchers with throwing-related shoulder pain. This research study supports that these patients are likely to have limited shoulder internal rotation in the 90/90 position. Six treatments over two weeks that included self-stretches with the sleeper stretch and horizontal adduction stretch, manual therapy with the sleeper stretch and horizontal adduction stretch, and throwing drills was found to be effective for improvement of GIRD and reducing throwing-related shoulder pain. Throwing drills with a focus on finish and follow through may improve GIRD, which was supported by this study to reduce throwing-related shoulder pain.

IMPLICATIONS FOR THE FUTURE

The future of research for baseball pitchers should be focused on injury prevention. Additional studies are needed to determine an effective maintenance program following treatment for GIRD over the course of a season with injury tracking to determine if the maintenance program reduces the incidence of throwing-related shoulder pain. Additional study of various treatment protocols is warranted to determine if others are effective for the treatment of GIRD and reduction of throwing-related shoulder pain. Also, a study with more frequent measurement of shoulder internal rotation in the 90/90 position would aid in determining optimal frequency and duration of treatment for correction of GIRD. Research studies on the efficacy of throwing drills for improving throwing biomechanics related to shoulder pain may need to be conducted over a longer period of time. Future research of additional biomechanical parameters along with those assessed in this study should be explored for relationships with shoulder pain.

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Chapter V

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