INVESTIGATION OF SHOULDER ROTATIONAL PROPERTIES AS RELATED TO INJURY HISTORY FOR COLLEGIATE BASEBALL PITCHERS

by

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ABSTRACT

MARC THOMAS DUEMMLER. Investigation of Shoulder Rotational Properties as Related to Injury History for Collegiate Baseball Pitchers.

(Under the direction of DR. NIGEL ZHENG)

Baseball is one of the most common sports played in the United States. It can be played starting as a child in the Little Leagues and pursued well into adulthood by the top players in Major League Baseball. Pitching in baseball produces tremendous stress on the shoulder joint, which commonly leads to injury. Additionally, this repetitive stress over time has shown to alter the shoulder rotational properties of the throwing arm.

The purpose of this study was to analyze the shoulder rotational properties of collegiate baseball pitchers and determine if they can be used to identify a history of upper extremity injuries. Shoulder rotational properties analyzed in this study that are common in the literature were glenohumeral internal rotation deficit (GIRD), total rotational motion (TRM) deficit, and a combination of those two deficits known as pathological GIRD. Additionally, a new variable was introduced (that analyzed the throwing arm exclusively) and is known as the external rotation to internal rotation ratio, or E/I ratio. The methods of this study involved collecting an injury questionnaire as well as collecting shoulder rotational properties with a custom sensor during a physical from Division I and Division II baseball pitchers.

The results of this study showed that neither GIRD, TRM deficit, not pathological GIRD had any statistically significant association with injury history. Therefore, these properties show potential in being used as return-to-play metrics following injury. However, the novel variable, E/I ratio, did have a statistically significant association with injury history. This statistical association showed that pitchers with a high E/I ratio were less likely to have a past injury.

Future work will analyze how these variables can be used to identify potential risk of future injury as opposed to identifying past injuries.

DEDICATION

I would like to dedicate this to my wife, Rebecca. She has been by my side throughout my entire academic journey. From senior year of high school, through undergrad, and now through my Master's Degree, she is my constant rock. I cannot thank her enough for all her love and support.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

E/I Ratio	External Rotation to Internal Rotation Ratio
EPA	End-Point-Angle
GIRD	Glenohumeral Internal Rotation Deficit
TRM	Total Rotational Motion

CHAPTER 1: INTRODUCTION

1.1 Background

Overhead throwing, like baseball pitching, generates tremendous forces and stresses on the human body, especially at the shoulder and elbow joints. It has been shown that maximum shoulder internal rotation torque can exceed 60 N-m and compressive forces and anterior shear forces can exceed 650 N and 350 N, respectively [1]. Repetitively generating such demands as those, it is not surprising that upper extremity injuries at the shoulder joint are common in overhead throwing athletes. Between 1998 and 2015, shoulder injuries were the top cause of Disabled List placement in Major League Baseball [2]. According to a study that analyzed the Disabled List of Major League Baseball players between the years 2011 and 2016, there were a total injuries of 3090. Of these, 511, or 17%, were shoulder injuries [3]. Pitchers are the most prone to injury; they account for approximately 78% of all injuries [3]. Common shoulder injuries include rotator-cuff tears, and superior labral anterior-to-posterior (SLAP) tears, and internal impingement [4].

Over the past 50 years, increased efforts have been placed on researching upper extremity injuries of overhead throwing athletes in order to reduce the number of injuries. One major discovery of this research was the physical examination finding of increased external rotation and decreased internal rotation in these athletes (Figure 1.1).

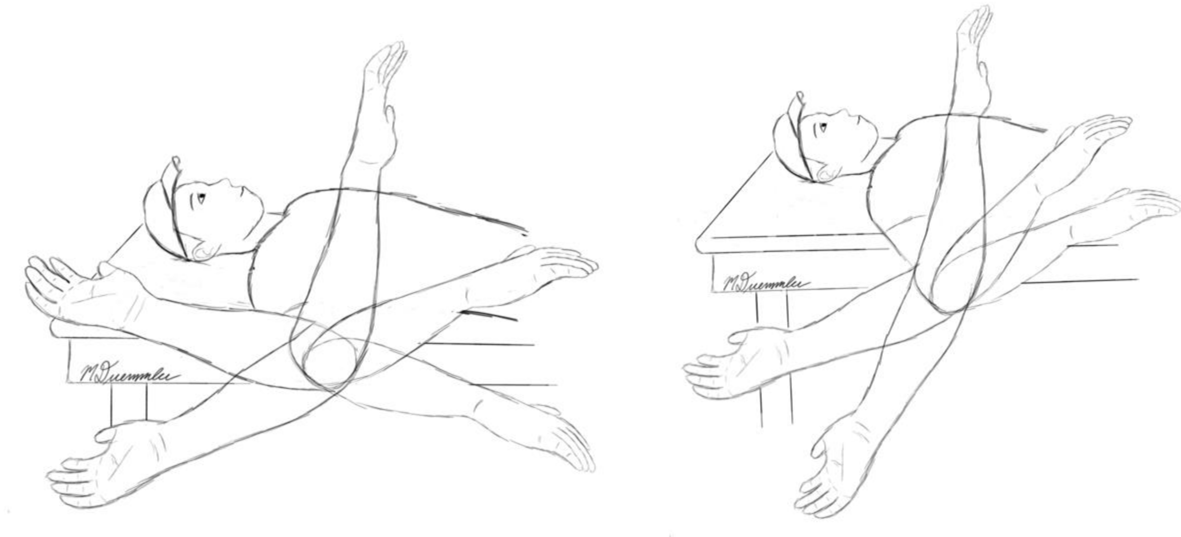

Figure 1.1: Shoulder range of motion. Left: Normal range of motion. Right: Increased external rotation and decreased internal rotation.

Popularized by Burkhart et al.'s three-part series on the disable throwing shoulder, the idea of glenohumeral internal rotation deficit (GIRD) has been a major focus of this research [4]. The commonly accepted definition of GIRD is a loss of 20 degrees of internal rotation compared to the contralateral shoulder. It has been shown that baseball pitchers with GIRD are more likely to be injured than those without, though without statistical significance [5].

In addition to GIRD, another more recent focus of research on overhead throwing athletes has been on total rotational motion (TRM). TRM is the summation of the external and internal rotation of the shoulder with the arm at 90 degrees of abduction. Wilk et al. determined that bilateral differences of more than 5 degrees in TRM was a statistically significant contributing factor to shoulder injuries in baseball pitchers [5].

The aim of this thesis is to use GIRD and TRM deficit as metrics to distinguish between pitchers who have had an upper extremity injury to those who have not. One drawback of using GIRD and TRM deficit to determine the impact of an injury history, is that both of these deficits rely on the nonthrowing shoulder. The shoulder rotational properties of the nonthrowing shoulder should not impact the likelihood of the throwing shoulder getting injured. For example, a pitcher with a flexible nonthrowing shoulder could have GIRD, but the deficit is due to increased internal rotation of the nonthrowing shoulder as opposed to decreased internal rotation of the throwing shoulder. Similarly, that same pitcher could have TRM deficit, but not because they lost TRM in their throwing arm. Rather, their nonthrowing arm just had increased TRM due to being more flexible than their throwing arm. Therefore, an aspect of this study will focus on the ratio of external rotation to internal rotation of the throwing arm exclusively (E/I Ratio).

1.2 Research Hypothesis

This experiment assumed a null hypothesis for three hypotheses. First, it was hypothesized that injury history is not related to GIRD at the collegiate level. Secondly, it was hypothesized that injury history is not related to TRM deficit at the collegiate level. Lastly, it was hypothesized that injury history is not related to the E/I Ratio of the throwing arm.

1.3 Objectives

In order to accept or reject the three hypotheses mentioned, six separate objectives will be investigated. The first objective of this study is to determine the prevalence of GIRD at the collegiate level. The second objective is to investigate the relationship between GIRD and injury history at the collegiate level. This includes any correlation, trends, or significant patterns between the two. The third objective is to investigate the prevalence of TRM deficit at the collegiate level. The fourth objective is to investigate the relationship between TRM deficit and injury history for collegiate baseball pitchers. Similar to the second objective, this includes any correlation, trends, or significant patterns. The fifth objective of this study is to investigate the relationship of pathologic GIRD, when both GIRD and TRM deficit are present, to injury history at the collegiate level. The final objective of this study is to investigate the relationship between the E/I Ratio of the throwing arm and injury history at the collegiate level.

1.4 Significance

The objective of this study is to determine the relationship that injury history has on the presence of anatomical GIRD, TRM deficit, pathological GIRD, and the E/I Ratio in collegiate baseball pitchers. TRM deficit and pathological GIRD have been studied for years and GIRD has been studied for decades. Therefore, this thesis will add to the literature surrounding these topics including the prevalence at the collegiate level and any potential relationship to injury history. The new variable that analyzes the external to internal rotation ratio of the throwing shoulder is novel to the baseball community. This thesis aims to determine how this new ratio relates to GIRD and TRM deficit. Lastly, by looking at injury history, this thesis will determine if these variables can be used for return-to-play metrics. If there are no significant differences between the injury history group and the group with no injury history, then these shoulder rotational properties can be used as an objective metric for determining return to play criteria.

CHAPTER 2: RELEVANT LITERATURE REVIEW

2.1 Anatomy and Biomechanics of the Shoulder Complex

To familiarize the reader with some of the terminology used in this thesis, the terms for anatomical direction will be introduced here (Figure 2.1). Superior is referring to the direction of the head and inferior is referring to the direction of the feet. An example of this would be the hips being superior to the knees whereas the ankles are inferior to the knees. The lateral direction is away from the body to the side and medial is towards the center of the body. An example of this would be your fibula being on the lateral side of your lower leg and your tibia being more medial. Distal is referring to the end of an appendage furthest from the body whereas proximal is referring to the end near the body. An example of this is the distal end of the arm is by your fingertips, and the proximal end of your arm is by your shoulder. Lastly, anterior is facing forward and posterior is referring to the backside. For example, the quadriceps are on the anterior side of the leg and the hamstrings are on the posterior side of the leg.

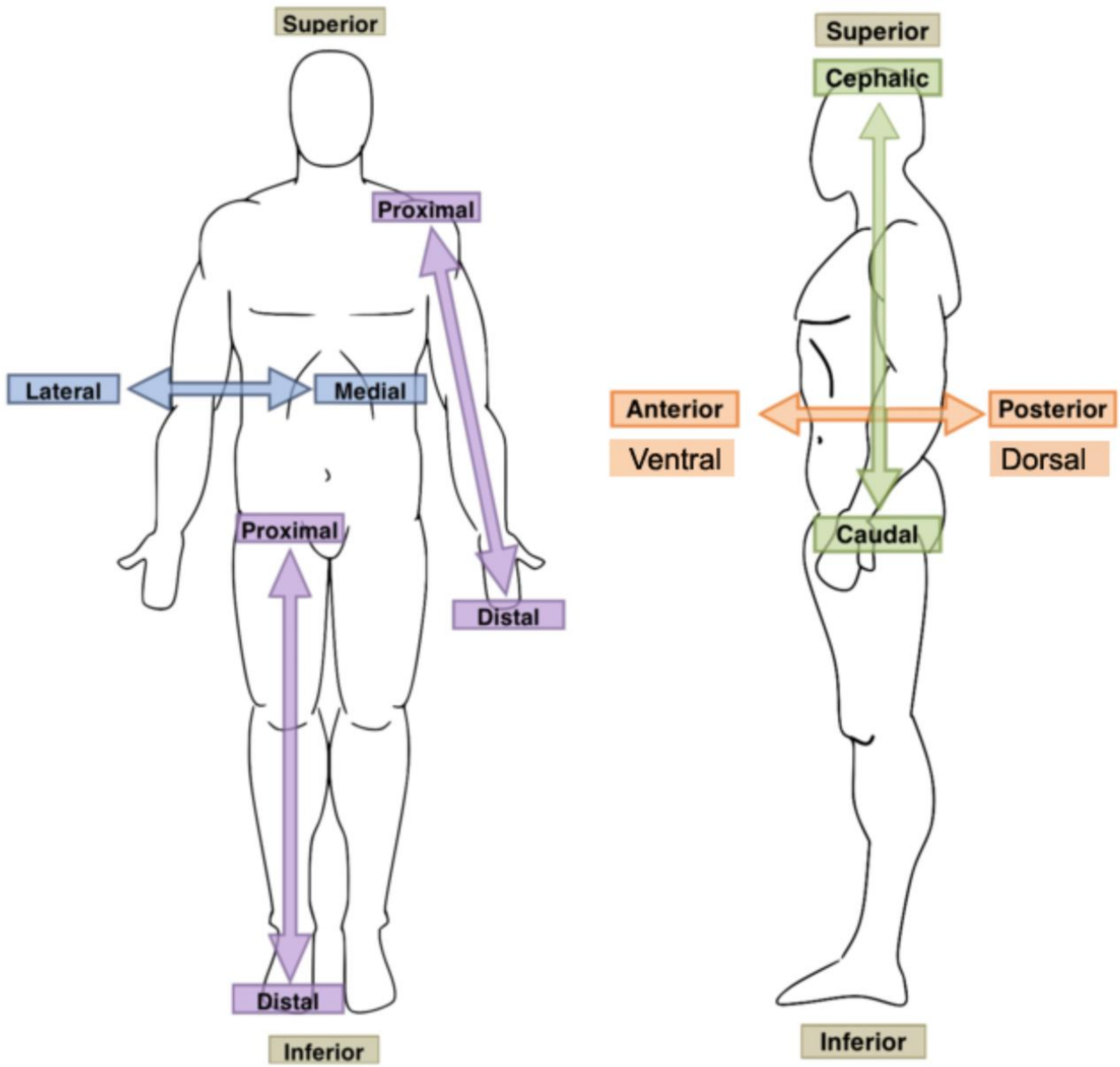

Figure 2.1: Anatomical directions and orientation (image adapted from [6]).

The shoulder has the greatest range of motion of any joint in the human body with around 180° of range of motion in most directions [7]. In order to provide clarity, a brief discussion of the types of rotation is warranted (Figure 2.2). Flexion of the shoulder is elevating the arm anteriorly (also known as forward elevation). Extension is reaching down and posterior (opposite of flexion). Abduction (also known as lateral elevation) is elevation of the arm next to the body. Adduction is the lowering of the arm laterally. External rotation is rotation along the axis of the humerus in the direction of the posterior side of the hand. Internal rotation is the opposite of external rotation where the rotation is in the direction of the palm. This thesis focuses mainly on internal and external rotation of the shoulder. Additionally, horizontal abduction and adduction are when the arm is rotated anteriorly and posteriorly with the arm at 90° of abduction (not shown in the figure).

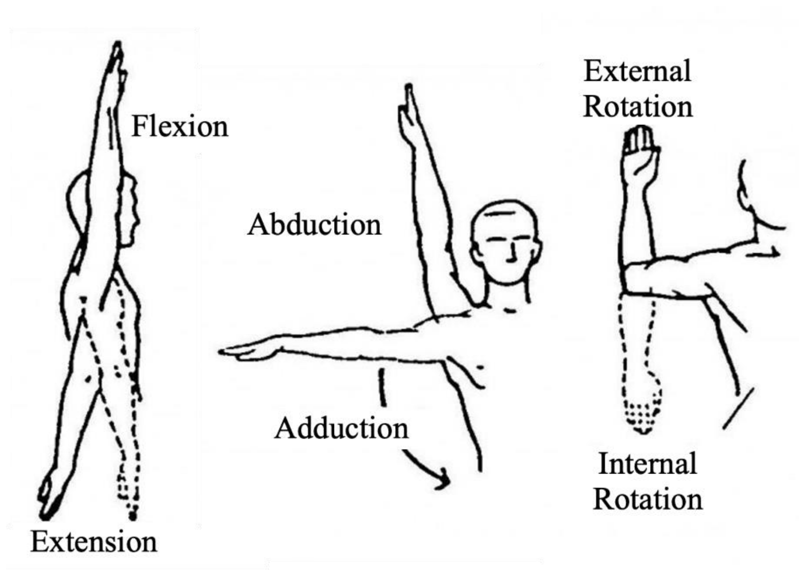

Figure 2.2: Shoulder range of motion (image adapted from [8]).

The shoulder complex consists of three bones: clavicle (collar bone), scapula (shoulder blade), and humerus (Figure 2.3). The scapula has two bony projections: the acromion and coracoid process. Additionally, the shoulder complex is composed of several joints including the sternoclavicular joint, acromioclavicular joint, and the glenohumeral joint. The glenohumeral joint is the main focus of this thesis as it is the shoulder joint where the glenoid of the scapula meets the head of the humerus.

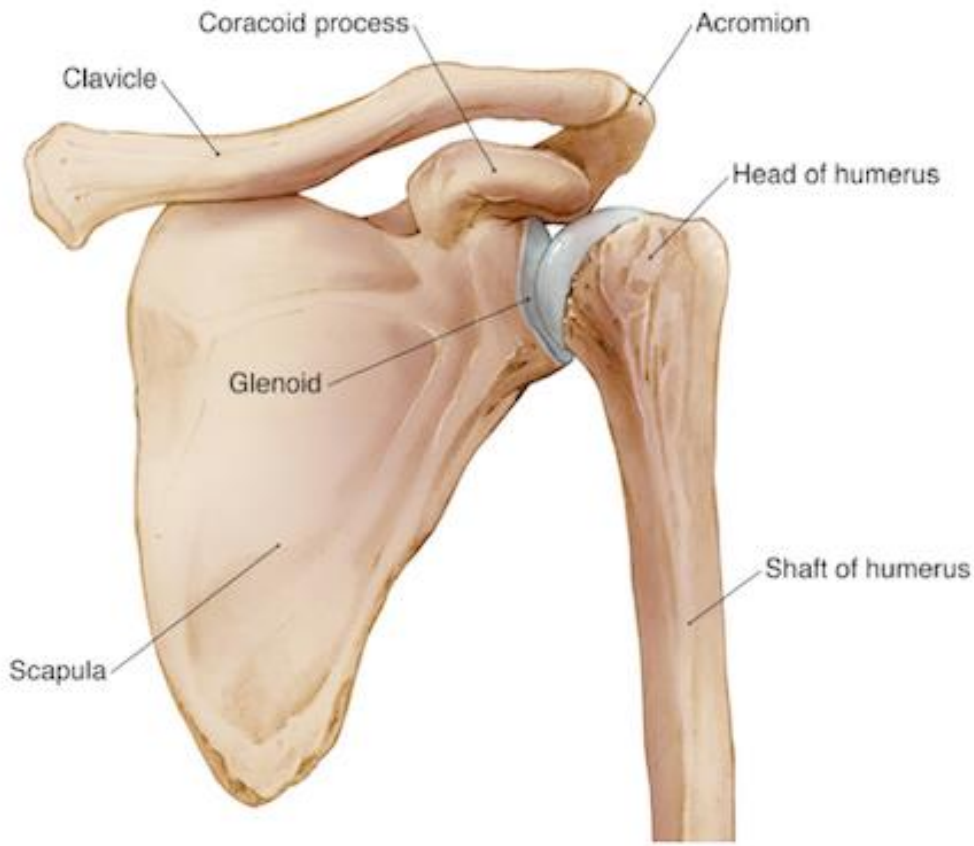

Figure 2.3: Bony anatomy of the shoulder (image adapted from [9]).

An important aspect of the glenohumeral joint is the glenoid labrum. The glenoid, which is found on the scapula, is a shallow socket where the head of the humerus sits. The glenoid labrum is a fibro-cartilaginous structure that surrounds the glenoid as well as deepens it (Figure 2.4) [9].The deepening of the socket provides additional joint stability, but still allows for the massive range of motion. The labrum will be further discussed in Section 2.2.2, where injuries to the labrum are introduced.

Figure 2.4: Glenoid labrum (image adapted from [9]).

Ligaments connect bone to bone and tendons connect bone to muscle. There are several important tendons in the shoulder complex that make up the rotator cuff. The rotator cuff is made of the tendons that connect the humerus to the supraspinatus, infraspinatus, subscapularis, and the teres minor muscles (Figure 2.5). The supraspinatus is the most superior of the rotator cuff muscles; it is connected to the posterior side of the scapula and then passes underneath the acromion to attach to the humeral head. The infraspinatus is inferior to the spine of the scapula. It is connected to the posterior side of the scapula and attaches to the posterior side of the humeral head. The teres minor is inferior to the infraspinatus and also attaches to the posterior side of the scapula and posterior side of the humeral head. Lastly, the subscapular is on the anterior side of the scapula and it attaches to the anterior side of the humeral head. The tendons of all these muscles form a ‘cuff’ around the shoulder.

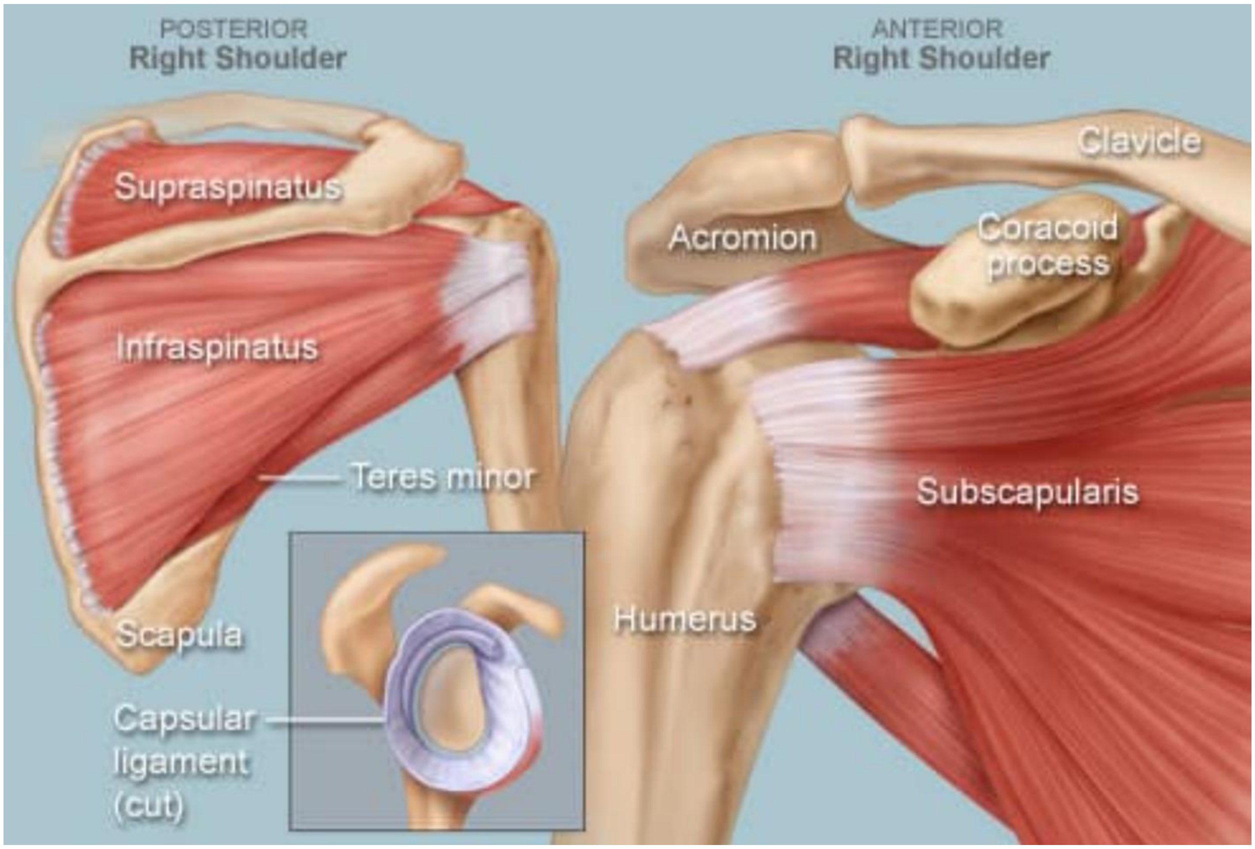

Figure 2.5: Shoulder anatomy (image adapted from [10]).

2.2 Common Throwing-Related Shoulder Injuries

Due to the repetitive, high demands on the shoulder during pitching, injuries are quite common. Among the injuries that are experienced by pitchers, this section will discuss three common injures: rotator cuff tears, superior labral anterior-to-posterior (SLAP) tears, and internal impingement [11].

2.2.1 Rotator Cuff Tears

As discussed in the previous section, rotator cuffs are the tendons that form a cuff around the shoulder. A rotator cuff tear is any sort of tear, whether internal, partial thickness, or full thickness to the rotator cuff (Figure 2.6) [12]. Rotator cuff tears are usually caused by repetitive microtrauma that occur during the throwing motion. Full-thickness tears are not common in the throwing athlete and very few athletes are able to return to play even after the fully torn cuff is repaired. Typical signs that a player has suffered a rotator cuff tear are diffuse pain in the shoulder and weakness and decreased velocity while throwing may also be noticed [12].

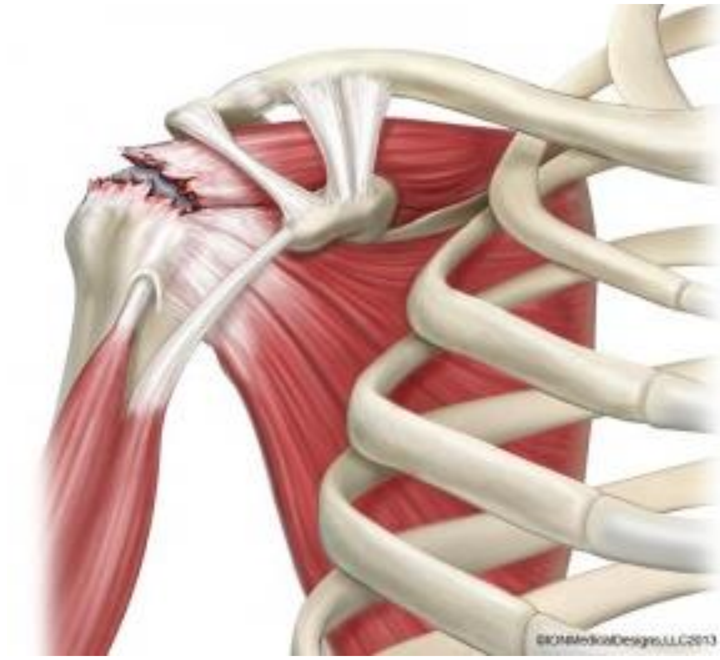

Figure 2.6: Rotator cuff tear (Image adapted from [13]).

2.2.2 SLAP Tears/ Lesions

Labral tears are common in overhead throwing athletes. A tear to the superior labrum and biceps anchor is called a superior labrum anterior to posterior (SLAP) tear or lesion (Figure 2.7). SLAP lesions are broken down into 10 types depending on the how the biceps anchor is involved and which portions of the labrum are affected. Treatments for SLAP tears can consist of rest and rehabilitation, but surgical intervention may be necessary.

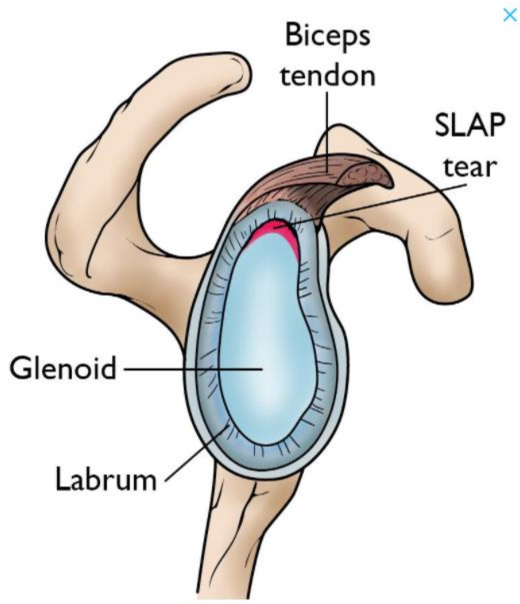

Figure 2.7: SLAP tear (Image adapted from [14]).

2.2.3 Internal Impingement

There are several types of impingements: subacromial or outlet impingement, secondary or nonoutlet impingement, coracoid impingement, and internal impingement. Internal impingement is when the articular side of the rotator cuff comes in contact with the posterior-superior labrum when the arm is abducted and externally rotated, such as the late-cocking phase of pitching (Figure 2.8) [12]. This impingement may be partially due to fatigue of the shoulder girdle. Athletes that have internal impingement typically experience pain on the posterior side of the shoulder.

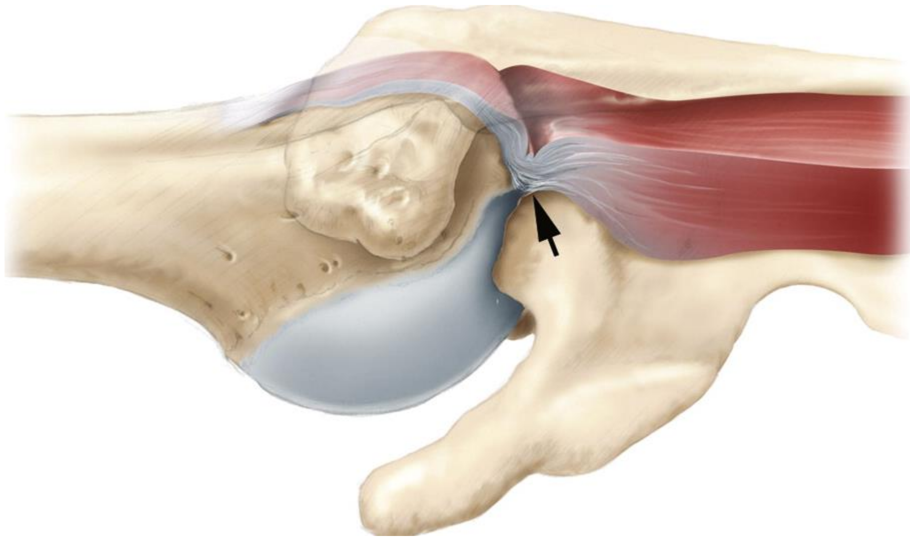

Figure 2.8: Internal impingement (Figure adapted from [15]).

2.3 Traditional Throwing-Related Physical Examination

The shoulder joint and shoulder rotational properties have been studied for several decades [4]. Physical examinations usually include strength tests, range of motion tests, as well as special tests as needed. Strength tests are used to determine deficiencies or irregularities of the rotator cuff and scapular muscles. These tests can include the lift-off test and belly press test [12]. There has been a traditional method of conducting range of motion tests to determine shoulder rotational properties that is commonly used in literature. In order to assess shoulder rotational properties in a clinical setting, a team physician will typically have the player in the supine position on an examination table with their arm at 90° of abduction and the elbow at 90° of flexion (Figure 2.9). The arm is then rotated until 'end feel' is perceived. At this point, a bubble goniometer is used to measure the angle of the arm [5]. One drawback of this technique is that shoulder tightness cannot be quantifiably measured. Therefore, a custom-made device was utilized in this study that measured force throughout the test. This device will be further discussed in Section 3.2.

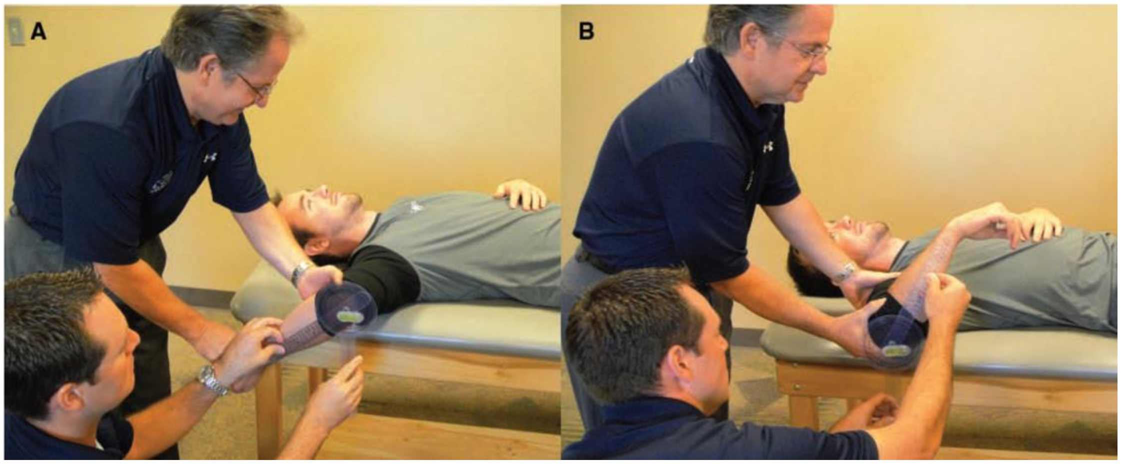

Figure 2.9: Traditional assessment of shoulder rotational properties. (A) Measurement of external rotation. (B) Measurement of internal rotation. Image adapted from [5].

Shoulder rotational properties commonly studied in the literature include external and internal range of motion, total rotational motion, shoulder rotational flexibility, humeral retrotorsion, and bilateral deficits of these properties, such as GIRD and TRM deficit. Bullock and colleagues conducted a systematic review of several of these shoulder rotational properties. They stated that internal rotation range of motion, internal rotation deficit, and total range of motion were all predictors of injury [16]. Stokes et al. determined that external rotation flexibility is associated with shoulder injuries that require surgery [17]. This study will focus on two specific topics common in literature, GIRD and TRM deficit.

2.4 Glenohumeral Internal Rotation Deficit

As mentioned earlier, increased external rotation and decreased internal rotation of the throwing arm compared to nonthrowing arm has been well established in literature [18-21]. This phenomenon is referred to as glenohumeral internal rotation deficit or GIRD. GIRD is defined as a loss of at least 20° of internal rotation of the shoulder compared to the contralateral shoulder [4, 5, 22].

At the professional level, it has been determined that repetitive stresses from throwing over time can alter glenohumeral rotational patterns without compromising the joint's stability [23]. Crockett et al. found that pitchers exhibit increased humeral head retroversion and external rotation and decreased internal rotation, where as non-throwers do not exhibit these characteristics [20]. Comparing the throwing and nonthrowing shoulder of professional baseball pitchers, Ellenbecker et al. found that there are differences in external and internal rotation between the two shoulders, but no differences in total range of motion [24]. When determining the effect that GIRD can have on injuries, Wilk et al. found that pitchers with GIRD are nearly twice as likely to be injured as those without GIRD, but without statistical significance [5]. In another study, Wilk determined that pitchers with GIRD were not significantly associated with future shoulder injury or surgery [22].

At the collegiate level, it has been established that pitchers exhibit similar characteristics as mentioned above. When comparing throwing and nonthrowing shoulders of collegiate baseball pitchers, there has been documented increased external rotation and humeral head retroversion and decreased internal rotation [25, 26]. To date, there are no studies that compare GIRD as indicator of future injury at the collegiate level. Internal and external rotation results of the throwing and nonthrowing arm can be seen in Table 2.1.

Table 2.1: Literature results of internal rotation EPA of the throwing and nonthrowing arm.

Author	Level	Throwing Arm Internal Rotation Range of Motion	Nonthrowing Arm Internal Rotation Range of Motion
Borsa et al. [19]	Professional	68.6 +/- 9.2	78.3 +/- 10.6
Borsa et al. [23]	Professional	59.7 +/- 7.0	68.2 +/- 8.6
Chant et al. [18]	Professional / College	57.1 +/- 8.7	73.5 +/- 9.6
Crockett et al. [20]	Professional	62. +/- 7.4	71 +/- 9.3
Ellenbecker et al. [24]	Professional	42.2 +/- 15.8	52.4 +/- 16.4
Hurd et al. [27]	High School	60 +/- 11	75 +/- 11
Meister et al. [28]	Little League	35.9 +/- 9.8	41.8 +/- 8.6
Osbahr et al. [26]	College	79.3 +/- 13.3	91.4 +/- 13.6
Reagan et al. [25]	College	43 +/- 7.4	51.2 +/- 7.3
Shanley et al. [29]	High School	53.4 +/- 11.4	61.4 +/- 9.9
Wilk et al. [5]	Professional	47.5 +/- 10.6	59.1 +/- 11.0
Wilk et al. [30]	Professional	52 +/- 12	63 +/- 12

2.5 Total Rotational Motion (TRM) Deficit

The ‘Total Motion Concept’ was introduced in 2002 Wilk et al. [31]. It states that that the sum of internal and external rotation of the throwing shoulder is equal (within 5°) compared to the nonthrowing shoulder. Other researchers have also found that total rotational motion is equal between the throwing and nonthrowing shoulder [24, 31]. Therefore, a total rotational motion (TRM) deficit is when a pitcher has at least a 5° deficit in total rotational motion comparing the throwing to the nonthrowing shoulder. Wilk found that a deficit of at least 5° in the throwing shoulder has a correlation to increased risk of injury for professional baseball pitchers. While some studies analyze shoulder rotational properties, no studies exist that relate TRM deficit to injury risk for collegiate baseball pitchers. Total rotational motion results of the throwing and nonthrowing arm found in literature can be seen in Table 2.2.

Table 2.2: Literature results of TRM of the throwing and nonthrowing arm

Author	Level	Throwing Arm TRM	Nonthrowing Arm TRM
Borsa et al. [19]	Professional	203.4 +/- 9.7	204.1 +/- 9.7
Borsa et al. [23]	Professional	195.2 +/- 12.1	198.6 +/- 26.6
Chant et al. [18]	Professional / College	171.1 +/- 12.5	177.6 +/- 11.0
Crockett et al. [20]	Professional	189 +/- 12.6	189 +/- 12.7
Ellenbecker et al. [24]	Professional	145.7 +/- 18.0	146.9 +/- 17.5
Hurd et al. [27]	High School	190 +/- 15	195 +/- 15
Meister et al. [28]	Little League	178.7 +/- 16.5	178.3 +/- 16.5
Osbahr et al. [26]	College	206.1	205.9
Reagan et al. [25]	College	159.5 +/- 12.4	157.8 +/- 11.5
Shanley et al. [29]	High School	179.1 +/- 16.4	179.2 +/- 14.8
Wilk et al. [5]	Professional	183.7 +/- 14.5	187.7 +/- 14.5
Wilk et al. [30]	Professional	184	190

2.6 Pathological GIRD

Not all GIRD is pathologic. Anatomical GIRD (described above) is when a player exhibits at least a 20° deficit of internal rotation comparing the throwing and nonthrowing shoulder. Pathological GIRD is when a player exhibits this loss of internal rotation in addition to a loss of total rotational motion [4]. In order words, pathological GIRD is when a player presents with a combination of anatomical GIRD (20° deficit of internal rotation) and TRM deficit (5° deficit of total rotational motion). The presence of pathological GIRD is thought to be a better determination of risk for future injury than anatomical GIRD alone [32].

CHAPTER 3: METHODOLOGY

3.1 Subject Recruitment

For this study, 177 Division I and Division II baseball pitchers were recruited. The protocol for this study was approved by an institutional review board at the University of North Carolina at Charlotte, and all pitchers gave written informed consent. This study included three components: an injury questionnaire, a physical examination, and biomechanical analysis with motion capture. The biomechanical analysis is not included in the scope of this thesis, but the result of the injury questionnaire and physical examination are discussed. The injury questionnaire recorded whether pitchers had any injuries or surgeries, their experience level, position (starter versus reliever), and if they were experiencing any pain. These questionnaires were filled out when the pitchers were tested and then during a follow-up visit one year later. The physical examination was conducted to determine the shoulder rotational properties of each pitcher.

3.2 Quantifying Shoulder Rotational Properties

Shoulder rotational properties were measured during a physical examination using a custom-made wireless device previously reported [33]. During the physical examination, pitchers were in the supine position with their arm abducted about 90° in coronal plane. The scapula was manually stabilized by applying a force to the player's coracoids process and scapula. The wireless device was attached to the distal end of the pitcher's forearm. The device was calibrated and validated to an error of less than 1.5° for orientation and 1 N for force measurement [33]. The device recorded arm orientation and force applied during testing at a rate of 100 Hz. The player's shoulder was rotated internally and externally to determine the range of motion (Figure 3.1).

Figure 3.1: Custom-made wireless device. Left: External rotation. Right: Internal rotation.

The player's internal rotation end-point-angle (EPA) is the angle at which 40 N of force were applied to rotate the arm internally. Similarly, the player's external rotation EPA is the angle at which 40 N of force were applied to rotate the arm externally. The summation of internal and external rotation is defined at the total rotational motion [31]. Any players that had a bilateral internal rotation EPA deficit of at least 20° were considered to have anatomical GIRD. Any players that had a bilateral TRM deficit of at least 5° were considered to have TRM deficit. Any pitchers that had both anatomical GIRD and TRM deficit were considered to have pathological GIRD. Due to the fact that both GIRD and TRM deficit include the shoulder rotational properties of the nonthrowing arm, a new variable is being introduced that focuses purely on the throwing arm: external rotation/internal rotation EPA ratio (E/I Ratio). This ratio is defined as the external rotation EPA divided by the internal rotation EPA of the throwing arm (Equation 1).

$$E/I\ Ratio = \frac{External\ Rotation\ EPA}{Internal\ Rotation\ EPA} \quad (1)$$

3.3 Statistical Analysis

All statistical analysis was performed using IBM SPSS Statistics Version 27 (SPSS, Chicago, IL). Due to non-normal distributions as determined by a Shapiro-Wilk test, non-parametric analyses were performed. For Objectives 1 and 3, a Wilcoxon signed-rank test was conducted to determine differences in internal rotation EPA and TRM between the throwing versus nonthrowing arm. For Objectives 2 and 4, a Mann-Whitney U Test was conducted to determine differences in internal rotation EPA and TRM between the GIRD and no GIRD groups and the TRM deficit and no TRM deficit groups for the throwing and nonthrowing arms. Objective 2 also included a Pearson product-moment correlation test to determine a correlation coefficient between throwing arm EPA and nonthrowing arm EPA and between the bilateral difference of internal rotation EPA and the E/I ratio. Similarly, Objective 4 utilized a Pearson product-moment correlation test to determine the correlation coefficient between throwing arm TRM and nonthrowing arm TRM and between the bilateral difference of TRM and the E/I ratio. Objectives 2, 4, and 5 also included a chi-square test of independence to assess whether GIRD or TRM deficit are associated with shoulder injury. Objective 5 also included a Kruskal-Wallis test to determine if there were statistical differences in shoulder rotational properties between 4 exclusive categorical groups. An alpha level of 0.05 was chosen for all statistical tests.

CHAPTER 4: RESULTS

4.1 Prevalence of GIRD

The first objective of this study was to determine the prevalence of GIRD at the collegiate level. Of the 177 pitchers analyzed in this study, 127 pitchers had a greater internal rotation EPA in their nonthrowing arm of at least 5°. Therefore, the majority of pitchers at the collegiate level are exhibiting at least some internal rotation deficit. A Shapiro-Wilk test was conducted to determine the normality of the throwing and nonthrowing arm internal rotation EPA. This analysis found that neither variable exhibited a normal distribution (throwing arm: p-value = 0.043, nonthrowing arm: p-value = 0.003). Due to non-normal distributions, a Wilcoxon signed-rank test was conducted to compare the medians of the internal rotation EPA for the throwing and nonthrowing arms. Data are medians unless otherwise stated. This analysis showed that there was a significant difference in median internal rotation EPA (-11.1°) between the throwing arm (72.4°) and nonthrowing arm (83.5°) internal rotation EPA, p-value < 0.005 (Figure 4.1).

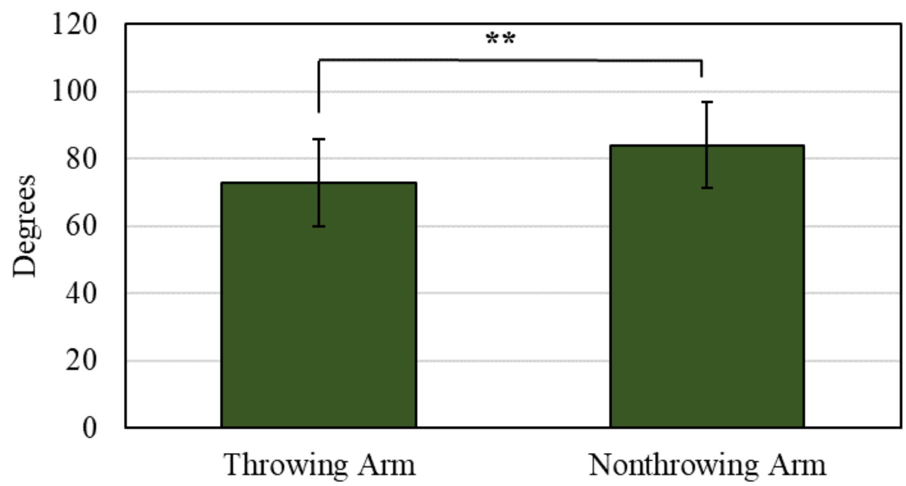

Figure 4.1: Internal rotation EPA of the throwing and nonthrowing arm. Error bars represent interquartile range. ** indicates a p-value < 0.01.

Out of the 177 pitchers recruited, a total of 38 pitchers met the clinical definition for anatomical GIRD, which is an internal rotation deficit of at least 20°. Of the 38 pitchers that had GIRD, 7 pitchers had an internal rotation deficit exclusively and 31 pitchers had both GIRD and TRM deficit (Table 4.1).

Table 4.1: Distribution of pitchers with and without GIRD.

	GIRD			No GIRD
	GIRD Only	Both Deficits	Total	
N	7	31	38	139
Percent (out of 177)	4.0 %	17.5 %	21.5 %	78.5 %

4.2 Injury History as Related to GIRD

The second objective of this study was to determine the relationship between GIRD and the occurrence of upper extremity injury. The first step was to compare the shoulder rotational properties between the GIRD and no GIRD groups. A Shapiro-Wilk test was conducted to determine the normality of the throwing and nonthrowing arm internal rotation EPA for the GIRD and no GIRD groups. This test found that the internal rotation EPA of the GIRD group for both the throwing and nonthrowing arm were normally distributed (p-value = 0.889 and p-value = 0.840, respectively), but the no GIRD group for the throwing and nonthrowing arm were not normally distributed (p-value = 0.003 and p-value = 0.010, respectively). Due to the non-normal distributions of some of the groups, a Mann-Whitney U Test was used to determine if there were differences in internal rotation EPA between the GIRD and no GIRD groups of the throwing arm. Distributions of internal rotation EPA for the two groups were not similar, as assessed by visual inspection. Internal rotation EPA for the GIRD group (median = 65.63°) and no GIRD group (median = 74.12°) were statistically significantly different, $U = 1710.0$, $z = -3.326$, $p < 0.001$ (Figure 4.2).

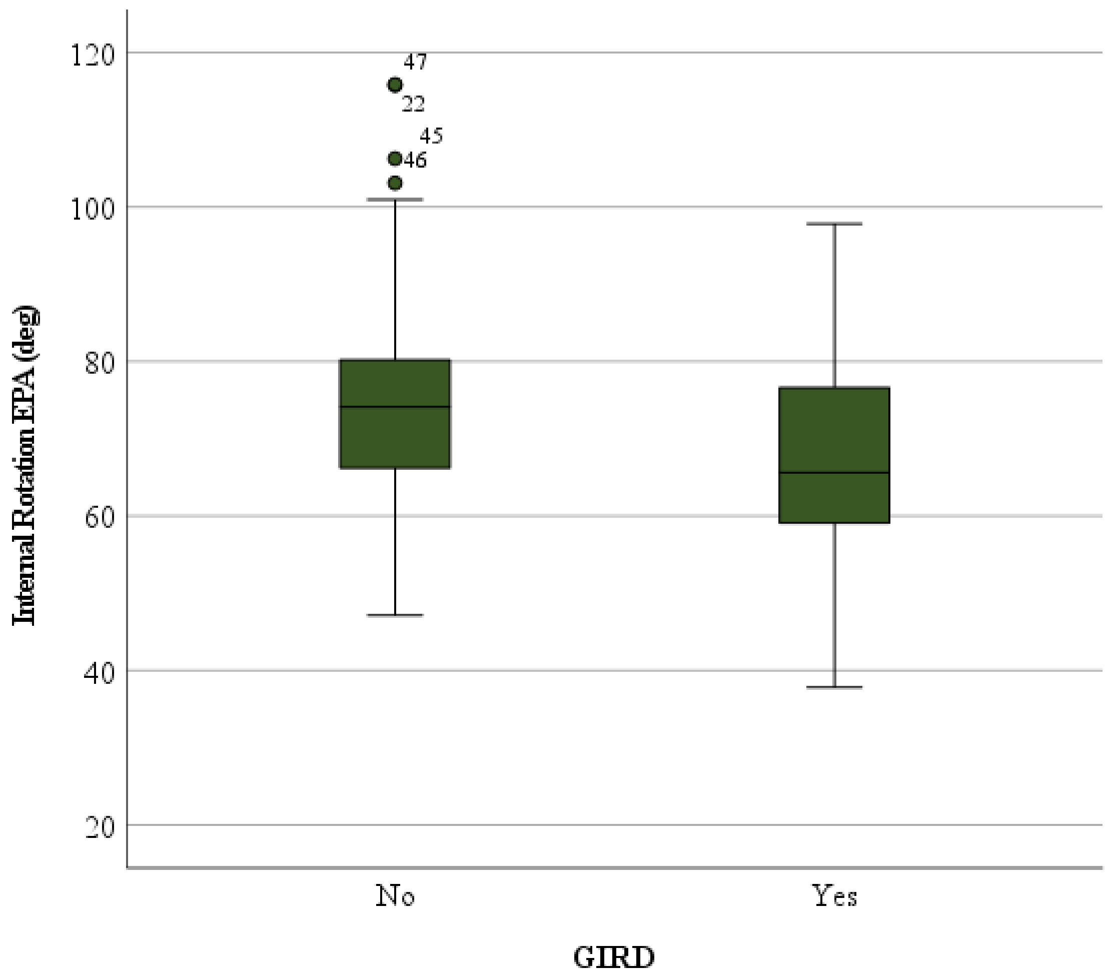

Figure 4.2: Throwing arm internal rotation EPA of the GIRD and no GIRD groups.

Similarly, a Mann-Whitney U Test was run to determine if there were differences in internal rotation EPA between the GIRD and no GIRD groups of the nonthrowing arm. Distributions of internal rotation EPA for the two groups were not similar, as assessed by visual inspection. Median internal rotation EPA for the GIRD group (92.10°) and no GIRD group (80.34°) were statistically significantly different, $U = 4022.0$, $z = 4.934$, $p < 0.001$ (Figure 4.3).

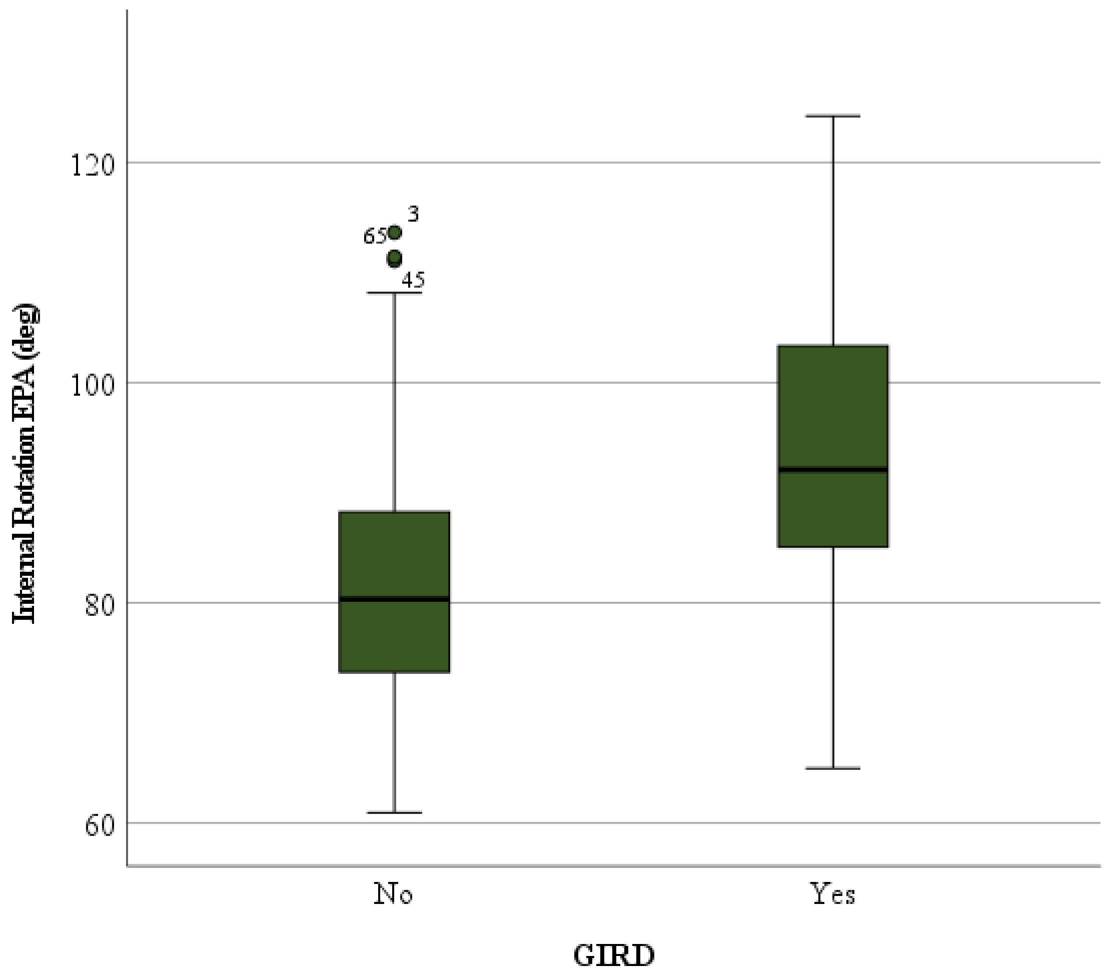

Figure 4.3: Nonthrowing arm internal rotation EPA of the GIRD and no GIRD groups.

Median internal rotation EPA for the throwing and nonthrowing arms for the GIRD and no GIRD groups can be seen in Table 4.2.

Table 4.2: Median internal rotation EPA of the throwing and nonthrowing arms. ** Indicates p-value < 0.01.

	GIRD		Total**
	Yes	No	
Throwing Arm**	65.63°	74.12°	72.37°
Nonthrowing Arm**	92.10°	80.34°	83.46°

A Pearson product-moment correlation test revealed that the throwing arm internal EPA has a significant correlation with nonthrowing arm internal EPA ($r = 0.553$, $p\text{-value} < 0.001$) (Figure 4.4). This indicates a strong, positive correlation between the two. Therefore, pitchers with high internal rotation EPA of the throwing arm will most likely have high internal rotation EPA of the nonthrowing arm, and vice versa.

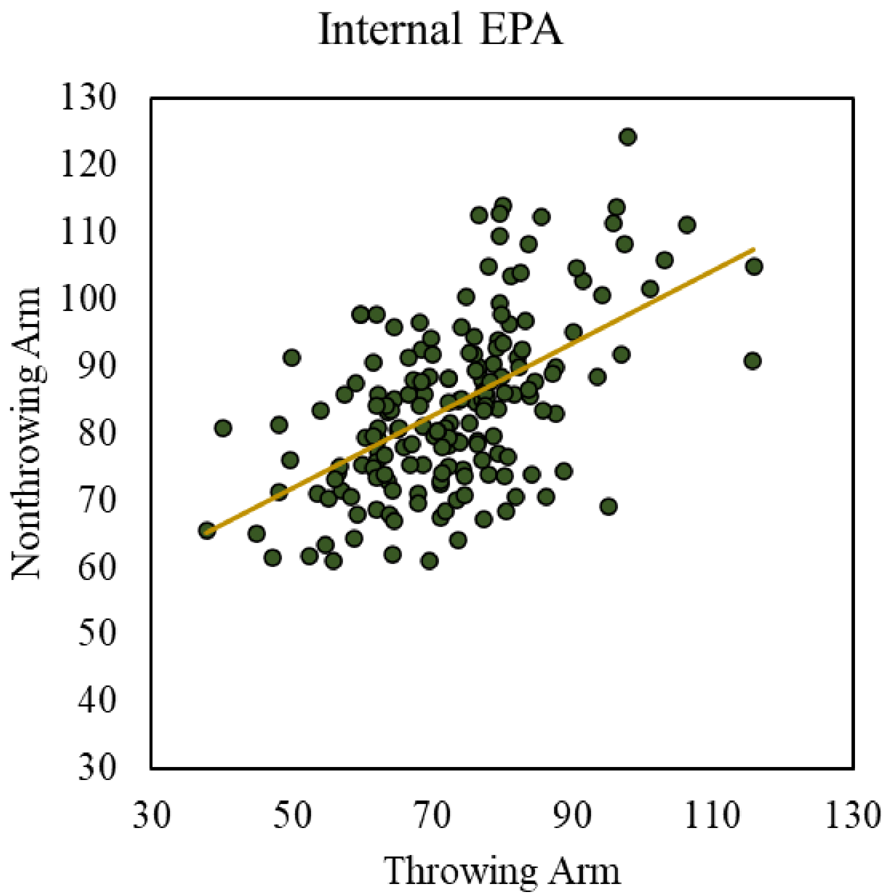

Figure 4.4: Scatterplot of throwing and nonthrowing arm internal rotation EPA.

Additionally, a Pearson product-moment correlation test revealed that the E/I Ratio has a significant correlation with bilateral difference of internal rotation EPA ($r = -0.488$, p-value < 0.001). This indicates a medium, negative relationship between E/I Ratio and bilateral internal rotation EPA. Therefore, pitchers who have increased GIRD (higher deficit) are correlated with a higher E/I Ratio.

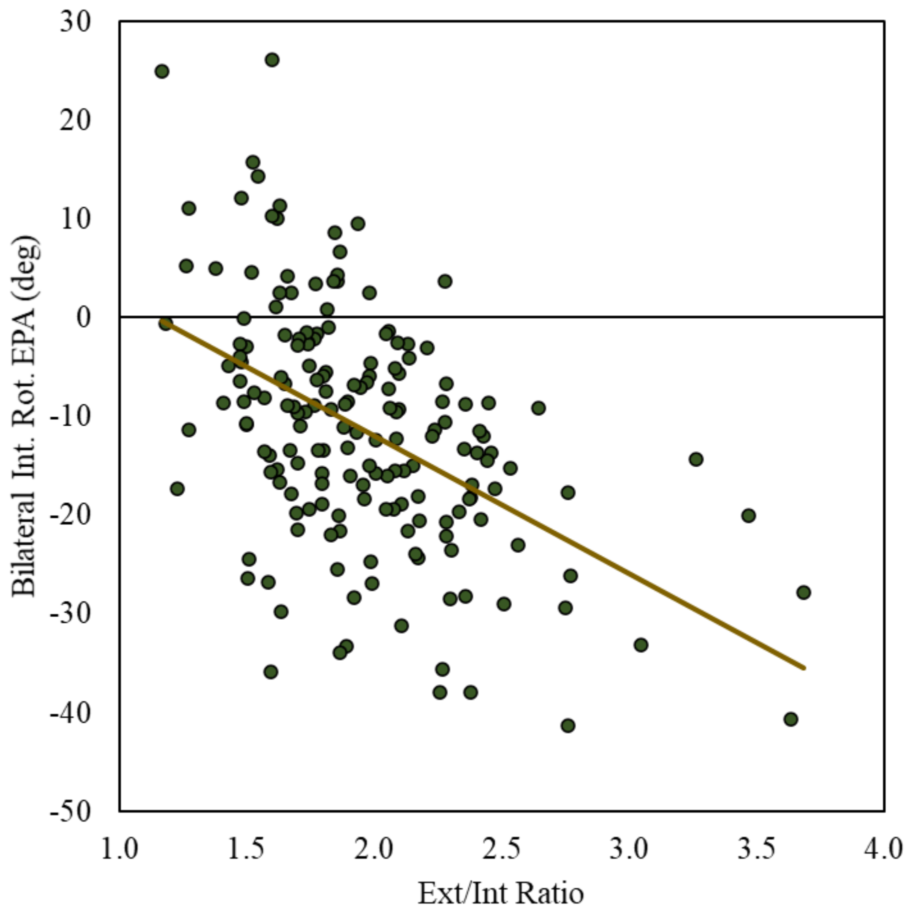

Figure 4.5: Scatterplot of bilateral internal rotation EPA and E/I Ratio.

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between the GIRD and no GIRD deficit groups and the injury groups: "no injury history" (n = 131) and "injury history" (n = 46) groups. All expected cell frequencies were greater than five. There was no statistically significant association between the deficit and injury groups ($\chi^2(1) = 0.613$, p-value = 0.434). This indicates that whether the pitchers had a GIRD or not, they were equally likely to fall into the no injury history or injury history groups.

Table 4.3: Distribution of pitchers with GIRD within injury history groups.

	No Injury History	Injury History
GIRD	30	8
No GIRD	101	38

Additionally, a Mann-Whitney U Test was utilized to determine if there were significant differences in bilateral internal rotation EPA comparing the no injury history and injury history groups. There was no significant difference in median bilateral internal rotation EPA between the injury history (9.38°) and no injury history (11.44°), p-value = 0.261.

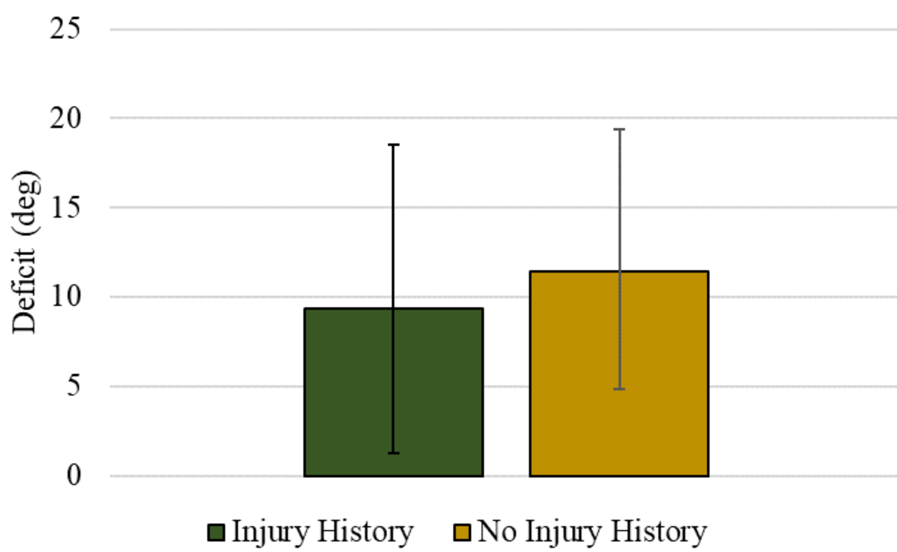

Figure 4.6: Median internal rotation EPA deficit of the throwing arm. Error bars represent interquartile range.

4.3 Prevalence of TRM Deficit

The third objective of this study was to determine the prevalence of TRM Deficit at the collegiate level. Of the 177 pitchers analyzed in this study, 97 pitchers had a greater TRM in their nonthrowing arm of at 2°. Therefore, roughly half of pitchers at the collegiate level have TRM deficit. A Shapiro-Wilk test was conducted to determine the normality of the throwing and nonthrowing arm TRM. This analysis found that neither variable exhibited a normal distribution (throwing arm: sig. = 0.042, nonthrowing arm: sig. = 0.013). Due to non-normal distributions, a Wilcoxon signed-rank test was conducted to compare the medians of the TRM for the throwing and nonthrowing arms. Data are medians unless otherwise stated. This analysis showed that there was a significant difference in median TRM (-5.3°) between the throwing arm (210.0°) and nonthrowing arm (211.4°) internal rotation EPA, p-value = 0.001.

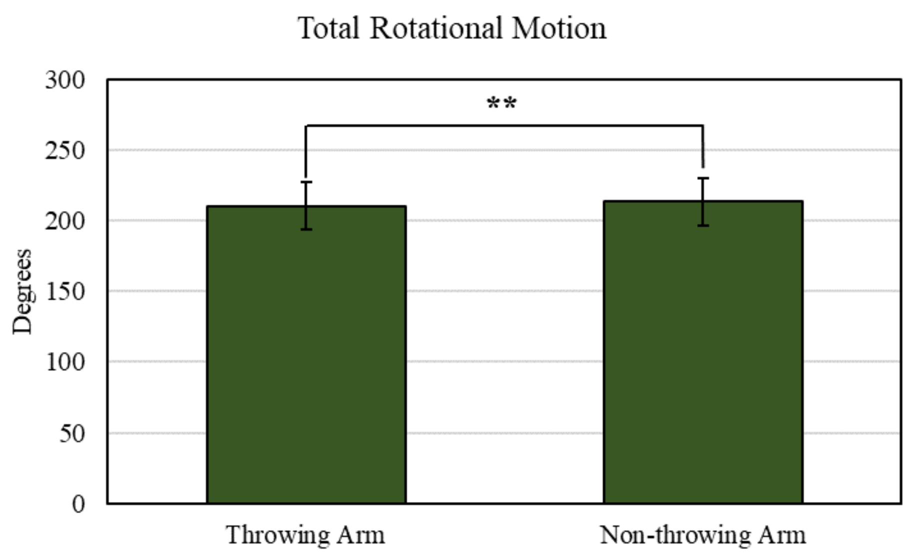

Figure 4.7: Total Rotational Motion of the Throwing and Nonthrowing Arms. Error bars represent interquartile range. ** indicates a p-value < 0.01.

Out of the 177 pitchers included in this portion of the analysis, a total of 89 pitchers had a TRM deficit of at least 5°. Of the 89 pitchers that had a TRM deficit, 58 pitchers exclusively had a TRM deficit and 31 pitchers had both GIRD and TRM deficit (Table 4.4).

Table 4.4: Distribution of pitchers with and without TRM Deficit.

	TRM Deficit			No TRM Deficit
	TRM Deficit Only	Both Deficits	Total	
N	58	31	89	88
Percent (out of 109)	32.8 %	17.5 %	50.3 %	49.7 %

4.4 Injury History as Related to TRM Deficit

The fourth objective of this study was to determine the relationship between TRM Deficit and the occurrence of shoulder injury. The first step was to compare the shoulder rotational properties between the TRM deficit and no TRM deficit groups. A Shapiro-Wilk test was conducted to determine the normality of the throwing and nonthrowing arm TRM for the TRM deficit and no TRM deficit groups. This test found that the TRM of the TRM deficit group for both the throwing and nonthrowing arm were normally distributed (p-value = 0.549 and p-value = 0.052, respectively), but the no TRM deficit group for the throwing and nonthrowing arm were not normally distributed (p-value = 0.015 and p-value = 0.006, respectively). Due to the non-normal distributions of some of the groups, a Mann-Whitney U Test was run to determine if there were differences in TRM between the TRM deficit and no TRM deficit groups of the throwing arm. Distributions of TRM for the two groups were similar, as assessed by visual inspection. Median TRM for the TRM deficit group (205.2) and no TRM deficit group (213.6) were statistically significantly different, $U = 2707.0$, $z = -3.547$, $p < 0.001$.

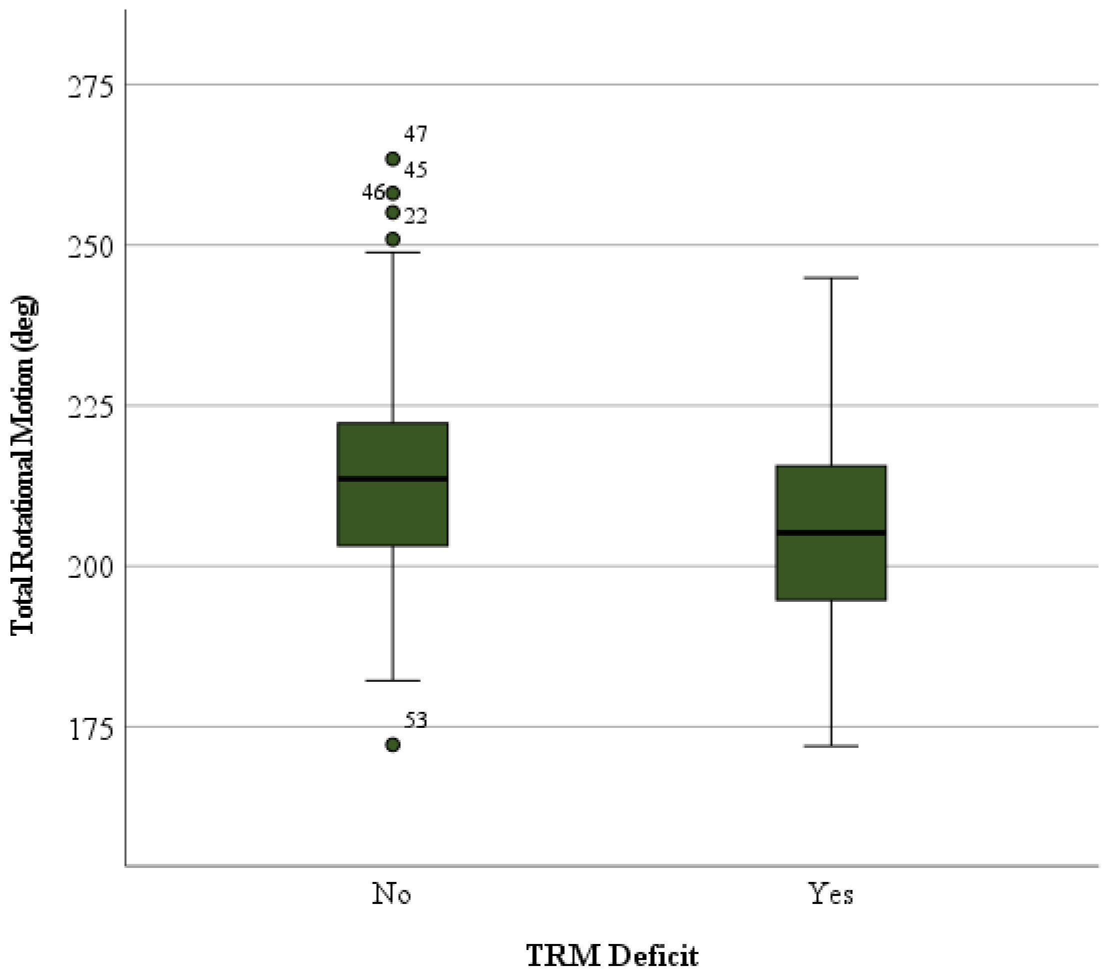

Figure 4.8: Total rotational motion of the throwing arm for the TRM deficit and no TRM deficit groups.

Similarly, a Mann-Whitney U Test was run to determine if there were differences in TRM between the TRM deficit and no TRM deficit groups of the nonthrowing arm. Distributions of TRM for the two groups were similar, as assessed by visual inspection. Median TRM for the TRM deficit group (219.5) and no TRM deficit group (204.9) were statistically significantly different, $U = 5847.0$, $z = 5.665$, $p < 0.001$.

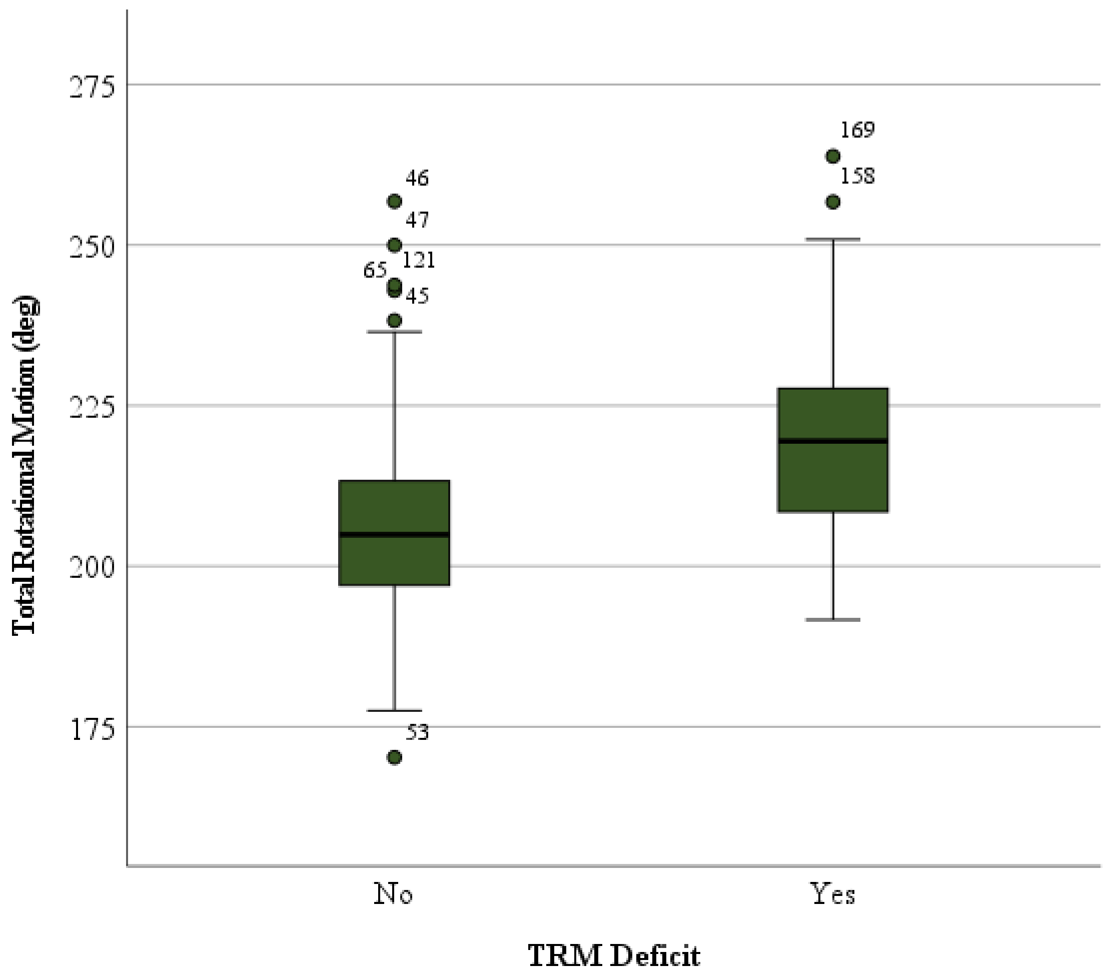

Figure 4.9: Total rotational motion of the nonthrowing arm for the TRM deficit and no TRM deficit groups.

Median TRM for the throwing and nonthrowing arms for the TRM deficit and no TRM deficit can be seen in Table 4.5.

Table 4.5: Median TRM of the throwing and nonthrowing arms. ** Indicates p-value < 0.01 for the row.

	TRM Deficit		Total**
	Yes	No	
Throwing Arm**	205.21°	213.61°	209.96°
Nonthrowing Arm**	219.50°	204.93°	211.36°

A Pearson product-moment correlation test revealed that the throwing arm TRM has a significant correlation with nonthrowing arm TRM ($r = 0.626$, p-value < 0.001) (Figure 4.10). This indicates a strong, positive correlation between the two. Therefore, pitchers with high TRM in the throwing shoulder will most likely have high TRM in the nonthrowing shoulder as well, and vice versa.

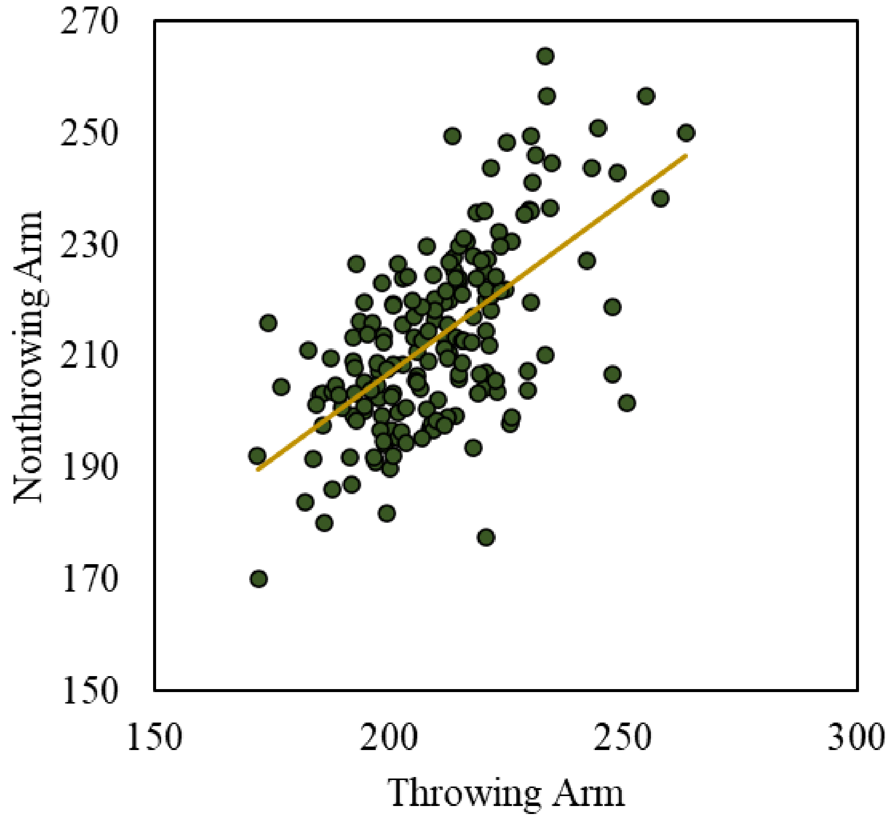

Figure 4.10: Scatterplot of Throwing and Nonthrowing arm TRM.

Additionally, a Pearson product-moment correlation test revealed that the E/I Ratio has a significant correlation with bilateral TRM ($r = -0.297$, p-value < 0.001). This indicates a weak, negative correlation between E/I Ratio and bilateral TRM. Therefore, pitchers who have increased TRM deficit (higher deficit) are correlated with a higher E/I Ratio.

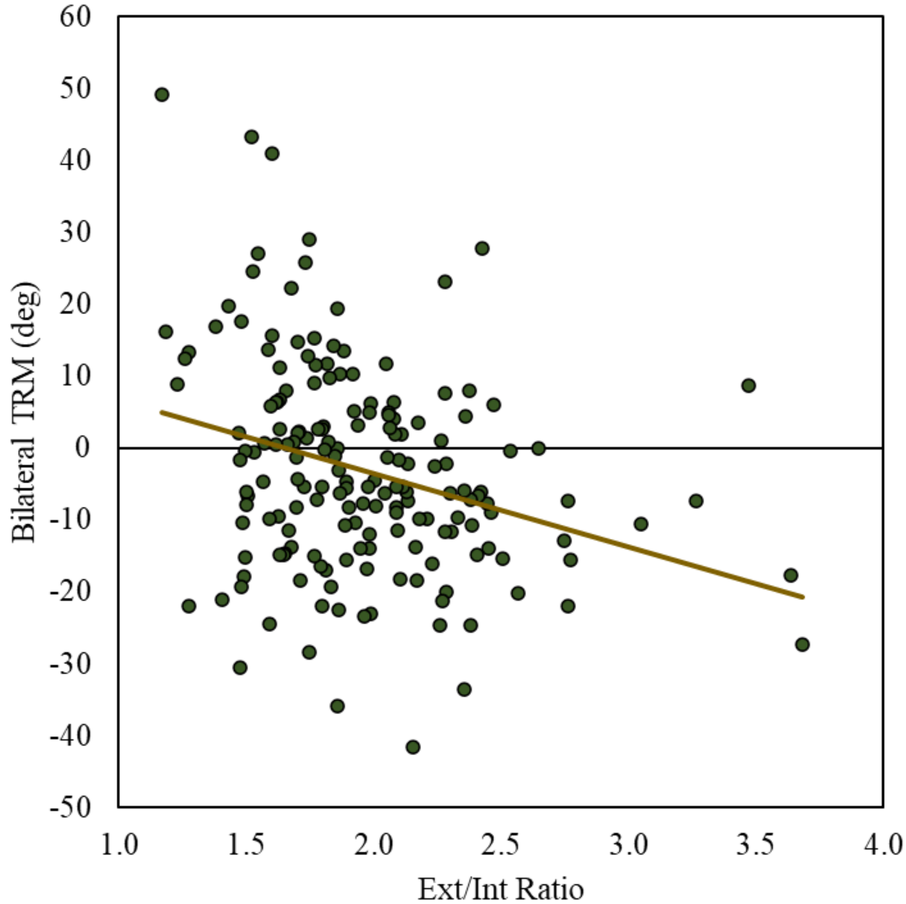

Figure 4.11: Scatterplot of Bilateral TRM and E/I Ratio.

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between the TRM deficit and no TRM deficit groups and the injury groups. All expected cell frequencies were greater than five. There was a not statistically significant association between the deficit and injury groups ($\chi^2(1) = 0.533$, p-value = 0.465). This indicates that whether the pitchers had a TRM deficit or not, they were equally likely to fall into the no injury history or injury history groups.

Table 4.6: Distribution of pitchers with TRM Deficit within injury group.

	No Injury History	Injury History
TRM Deficit	68	21
No TRM Deficit	63	25

Additionally, a Mann-Whiney U Test was utilized to determine if there were significant differences in TRM between the no injury history group and injury history group. The statistical test showed that there were no significant differences in median TRM for the injury history group (1.47°) and no injury history group (5.48°), p-value = 0.565. Therefore, once the healthy pitchers were tested, there were no differences in TRM for those who had injury history and those that did not.

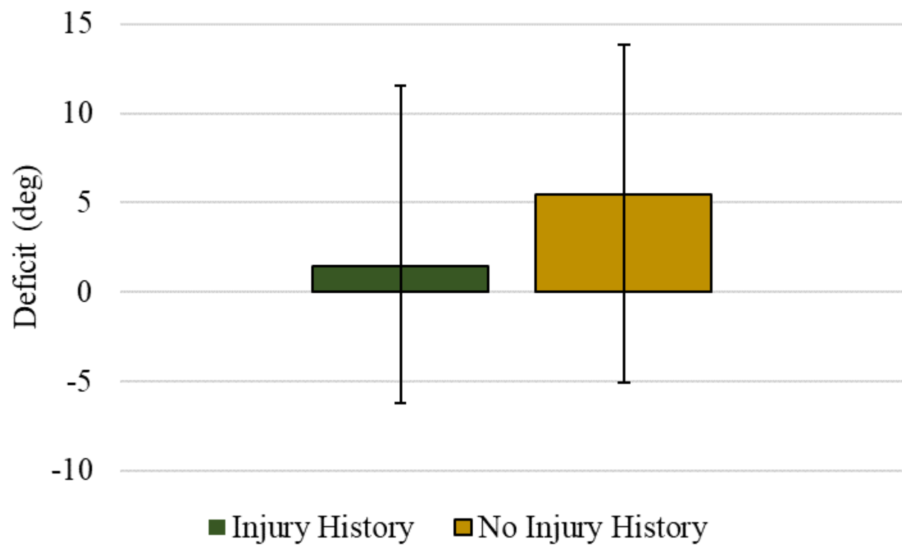

Figure 4.12: Median TRM deficit of injury history groups. Error bars represent interquartile range.

4.5 Injury History as Related to Pathological GIRD

The fifth objective of this project was to determine the impact of pathological GIRD, or when a player has both anatomical GIRD and TRM deficit. This was accomplished by dividing the pitchers into four exclusive groups: the "both deficits" (n = 31), "GIRD only" (n = 7), "TRM deficit only" (n = 58), and "neither deficit" (n = 81) groups. Then the shoulder rotational properties of each group were determined. A Kruskal-Wallis test was conducted to determine if there were differences in throwing arm internal rotation EPA between the four exclusive deficit groups. Distributions of internal rotation EPA were similar for all groups, as assessed by visual inspection. Median internal rotation EPA were statistically different between the deficit groups ($H(3) = 23.427$, $p < 0.001$). Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed a statistically significant differences between the neither deficit (77.0) and both deficit (64.7) ($p < 0.001$), and the neither deficit and TRM deficit only (71.0) ($p = 0.005$), but not between the neither deficit and GIRD only (69.9) or any other group combination.

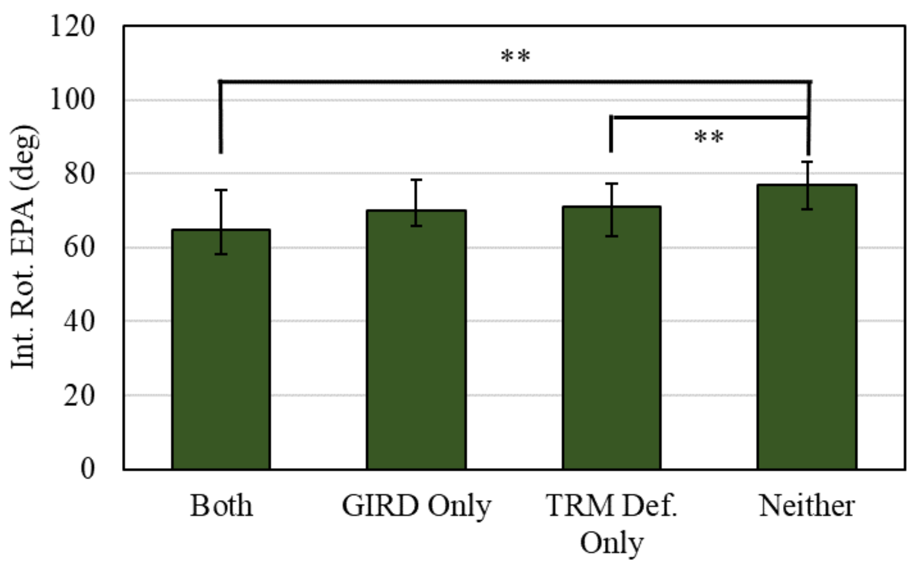

Figure 4.13: Internal rotation EPA of the throwing arm for the exclusive deficit groups. Error bars represent interquartile range. ** Indicates p-value < 0.01.

A Kruskal-Wallis test was conducted to determine if there were differences in nonthrowing arm internal rotation EPA between the four exclusive deficit groups. Distributions of nonthrowing arm internal rotation EPA were similar for all groups, as assessed by visual inspection. Median internal rotation EPA were statistically different between the deficit groups ($H(3) = 24.874$, $p < 0.001$). Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed a statistically significant differences between the both deficit (91.3) and neither deficit (79.4) ($p < 0.001$), and the both deficit and TRM deficit only groups (81.1) ($p = 0.001$), but not between the both deficit and GIRD only (95.8) or any other group combination.

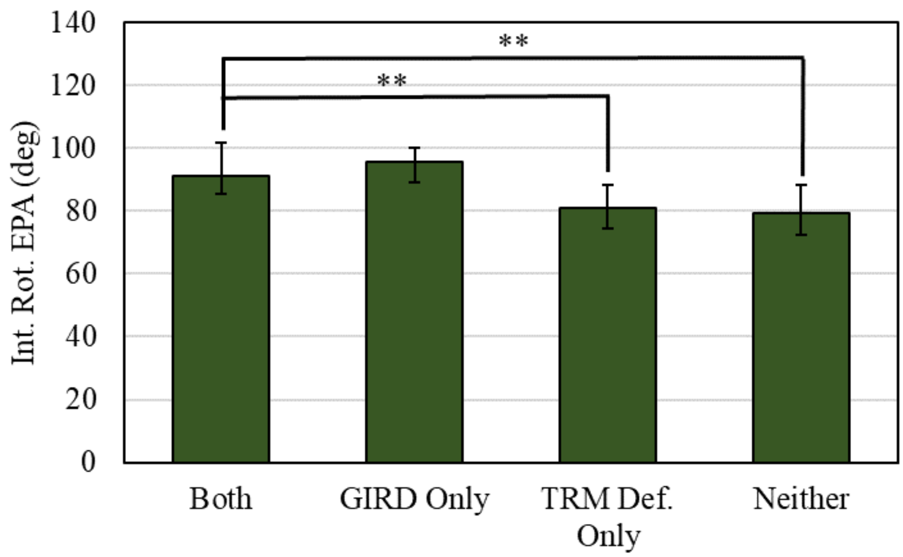

Figure 4.14: Internal rotation EPA of the nonthrowing arm for the exclusive deficit groups. Error bars represent interquartile range. ** Indicates p-value < 0.01.

A Kruskal-Wallis test was conducted to determine if there were differences in throwing arm TRM between the four exclusive deficit groups. Distributions of TRM were similar for all groups, as assessed by visual inspection. Median TRM were statistically different between the deficit groups ($H(3) = 12.606$, $p = 0.006$). This post hoc analysis revealed a statistically significant differences between the TRM deficit only (206.2) and neither deficit (214.2) ($p = 0.009$), but not between the both deficit (202.9) and GIRD only (212.6) or any other group combination.

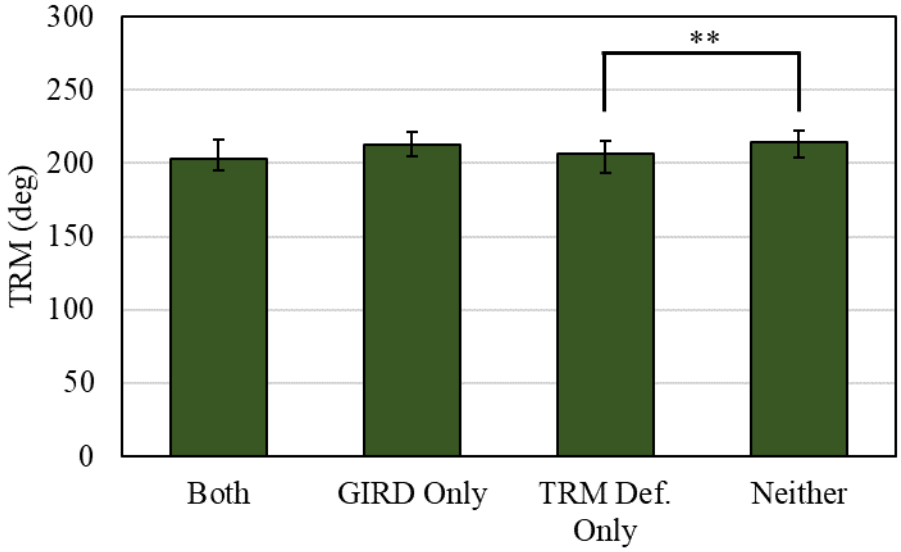

Figure 4.15: TRM of the throwing arm for the exclusive deficit groups. Error bars represent interquartile range. ** Indicates p-value < 0.01.

A Kruskal-Wallis test was conducted to determine if there were differences in nonthrowing arm TRM between the four exclusive deficit groups. Distributions of nonthrowing arm TRM were similar for all groups, as assessed by visual inspection. Median internal rotation EPA were statistically different between the deficit groups ($H(3) = 33.510$, $p < 0.001$). Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed a statistically significant differences between the neither deficit (204.4) and both deficit (224.0) ($p < 0.001$), and the neither deficit and TRM deficit only (217.2) ($p < 0.001$), but not between the neither deficit and GIRD only (207.2) or any other group combination.

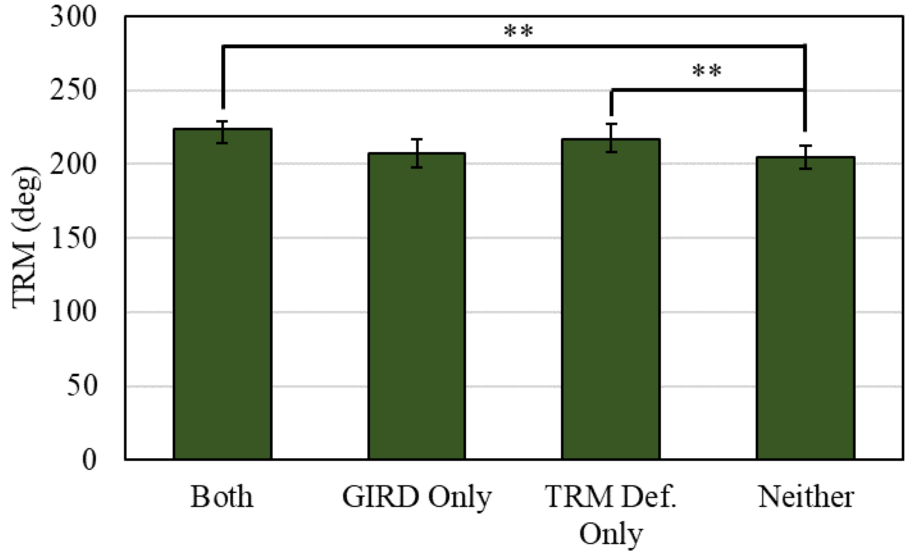

Figure 4.16: TRM of the nonthrowing arm for the exclusive deficit groups. Error bars represent interquartile range. ** Indicates p-value < 0.01.

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between the exclusive deficit groups and injury groups. One expected cell frequency was less than five. There was no statistically significant association between the deficit and injury groups ($\chi^2(3) = 5.795$, p-value = 0.122). This indicates that regardless of the deficit group that pitchers fell into, they were equally likely to fall into the no injury history or injury history groups.

Table 4.7: Distribution of pitchers in exclusive deficit within injury group.

	No Injury History	Injury History
Both Deficit	25	6
GIRD Only	6	1
TRM Deficit Only	47	11
Neither Deficit	53	28

4.6 Impact of Shoulder External/Internal Rotation Ratio

The final objective of this thesis was to determine the impact of the novel E/I ratio. Therefore, a Mann-Whitney U Test was utilized to determine if there were significant differences in E/I Ratio comparing the no injury history and injury history groups. There was no significant difference in median E/I Ratio between the injury history (1.87) and no injury history (1.88), p-value = 0.867. All pitchers were healthy at the time of testing and these results indicate that there is no significant difference in bilateral internal rotation EPA and E/I Ratio in the pitchers who had injury history and those did not.

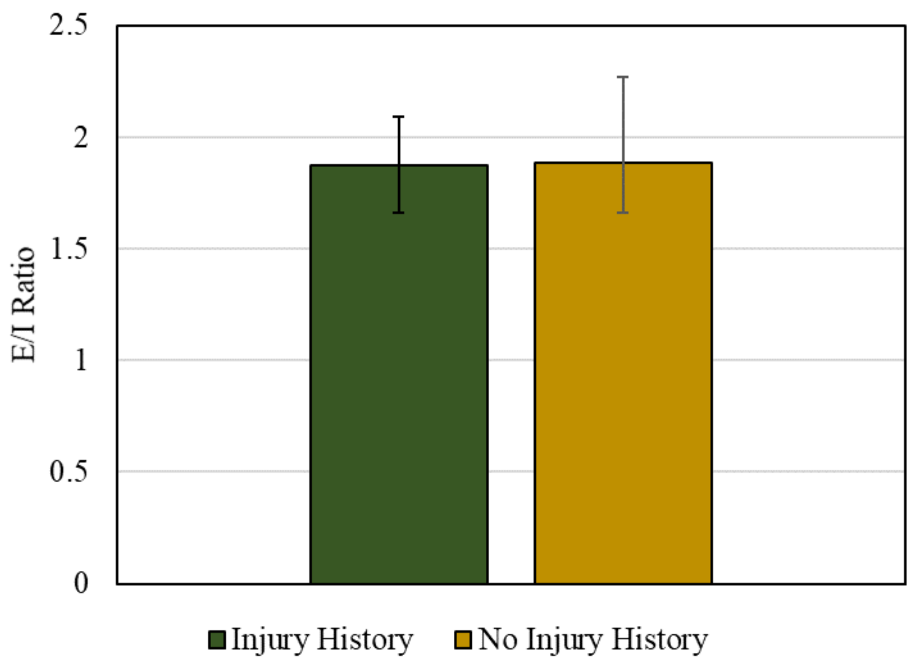

Figure 4.17: Median E/I ratio of the throwing arm. Error bars represent interquartile range.

The average E/I ratio for a pitcher who had no history of injury was 1.97 ± 0.44. Therefore, pitchers were considered to have a high E/I ratio if their E/I ratio was greater than one standard deviation above the mean, or greater than roughly 2.4.

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between pitchers who had a high E/I Ratio (greater than 2.4) and low E/I Ratio and injury groups (Table 4.8). One expected cell frequency was less than five. There was a statistically significant association between the deficit and injury groups ($\chi^2(1)$ = 5.582, p-value = 0.018). This indicates that there is a statistically significant association between injury history and E/I Ratio.

Table 4.8: Distribution of pitchers with high and low E/I Ratios based on GIRD.

	No Injury History	Injury History
E/I Ratio $\geq$ 2.4	20	1
E/I Ratio $<$ 2.4	111	45

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between pitchers who had GIRD, TRM deficit, and an E/I greater than 2.4 (Table 4.9). One expected cell frequency was less than five. There was no statistically significant association between the deficit and injury groups ($\chi^2(1)$ = 1.091, p-value = 0.296). This indicates that there is no statistically significant association between injury history and a pitcher having GIRD, TRM deficit, and a high E/I ratio.

Table 4.9: Distribution of pitchers with pathological GIRD and a high E/I Ratio.

	No Injury History	Injury History
GIRD + TRM Deficit + E/I Ratio $\geq$ 2.4	8	1
Not all 3 risk factors	123	45

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between pitchers who had both GIRD and an E/I greater than

2.4 (Table 4.10). One expected cell frequency was less than five. There was no statistically significant association between the deficit and injury groups ($\chi^2(1) = 1.409$, p-value = 0.235). This indicates that there is no statistically significant association between injury history and a pitcher having both GIRD and a high E/I ratio.

Table 4.10: Distribution of pitchers with anatomical GIRD and a high E/I Ratio.

	No Injury History	Injury History
GIRD + E/I Ratio ≥ 2.4	9	1
Not both risk factors	122	45

A Pearson chi-square test for association was conducted to determine if there was a statistically significant association between pitchers who had both TRM deficit and an E/I greater than 2.4 (Table 4.11). One expected cell frequency was less than five. There was no statistically significant association between the deficit and injury groups ($\chi^2(1) = 3.563$, p-value = 0.059). This indicates that there is no statistically significant association between injury history and a pitcher having both TRM deficit and a high E/I ratio.

Table 4.11: Distribution of pitchers with TRM Deficit and a high E/I Ratio.

	No Injury History	Injury History
TRM Deficit + E/I Ratio ≥ 2.4	15	1
Not both risk factors	116	45

4.7 Case Studies

There are several individual pitchers that will be highlighted in this section to comment on the relationship between GIRD, TRM deficit, and the new variable: E/I Ratio. The first pitcher had the largest E/I ratio (3.68), also had an internal rotation EPA deficit and TRM deficit of 27.80° and 27.36°, respectively. This pitcher did report an injury when filling out the injury questionnaire and therefore falls into the injury history group. Based on literature findings, this pitcher would be considered a 'high risk' pitcher because he has pathological GIRD, but interestingly, this pitcher did not sustain any injury over the course of the next year.

Another pitcher who reported that they underwent surgery at the one-year follow-up had an internal rotation EPA deficit of 20.02°, but actually had a TRM *surplus* of 8.75°. Therefore, this pitcher has anatomical GIRD but not TRM deficit. This pitcher had an E/I ratio of 3.47, which is above the 2.4 threshold. A slightly different case had a pitcher with a massive TRM deficit of 41.66°, but an internal rotation EPA deficit of only 15.03° and an E/I ratio of only 2.15. This pitcher did not have an injury at the initial questionnaire or at the one-year follow-up. Therefore, using GIRD and the E/I ratio could show promise in determining risk of future injuries/surgeries.

At the one-year follow-up, another pitcher reported having suffered an injury. This pitcher had an internal rotation EPA deficit of only 13.71°, but a TRM deficit of 8.95°. Therefore, this pitcher has a TRM deficit, but not GIRD. This pitcher had an E/I Ratio of 2.46, which is above the 2.4 threshold. Therefore, using TRM deficit and the E/I ratio could show promise in determining risk of future injuries/surgeries. Another pitcher had an E/I ratio of 3.27 and a TRM deficit of 7.44°, but an internal rotation EPA deficit of only 14.32° reported no injuries or surgeries at the initial questionnaire or at the one-year follow-up. This pitcher had both TRM deficit and a high ratio, but ended up not having any injuries or surgeries.

Lastly, one pitcher had pathological GIRD with an internal rotation EPA deficit of 35.86° and a TRM deficit of 24.45°, but only had an E/I ratio of 1.59. This pitcher reported no injuries or surgery at the initial questionnaire or at the one-year follow-up. Therefore, using the E/I ratio shows how bringing the nonthrowing arm into the equation can skew potential risk factors. There could be a potential future where the E/I ratio is used in tandem with either GIRD or TRM deficit or both of those deficits.

CHAPTER 5: DISCUSSION

5.1 Overall Summary

The first hypothesis of this thesis was that injury history is not related to GIRD at the collegiate level. This null hypothesis was accepted as shown in Section 4.2 with the results of the Pearson chi-square test for association. The second hypothesis was that injury history is not related to TRM deficit at the collegiate level. This null hypothesis was accepted as shown in Section 4.4 with results of the Pearson chi-square test for association. The final hypothesis was the injury history is not related to E/I Ratio at the collegiate level. This null hypothesis was rejected as shown in Section 4.6 with results of the Pearson chi-square test for association. All of these results will be further discussed individually during the remainder of this chapter.

5.2 Injury History as Related to GIRD

Objectives 1 and 2 were used to address the first hypothesis that there is no relationship between injury history and the presence of GIRD. The first objective was to determine the prevalence of GIRD at the collegiate level. Osbahr et al. found that all of their 19 male college baseball pitchers had greater external rotation and decreased internal rotation in the dominant shoulder [26]. Our findings are similar to these in that the majority of our pitchers had these same traits. The results of this study show that around 72% of pitchers have a bilateral internal rotation deficit of at least 5°, and that 21% of pitchers meet the criteria for anatomical GIRD (at least 20° bilateral deficit). Therefore, GIRD is present at the collegiate level.

The second objective was to determine if there was any association between injury history and the presence of GIRD. In order to accomplish this, it was first demonstrated that the shoulder rotational properties of the GIRD and no GIRD groups were statistically different from one another. For the throwing shoulder, the median internal rotation EPA for the GIRD group

(64.50°) was significantly different than the no GIRD group (74.12°), p-value < 0.001. Additionally, the median internal rotation EPA of the nonthrowing shoulder for the GIRD group (92.10°) was significantly different than the no GIRD group (80.34°), p-value < 0.001. Additionally, the median throwing arm internal rotation EPA (72.37°) was significantly different than the nonthrowing arm internal rotation EPA (83.46°). The median deficit of around 11° matches well with what is found at the collegiate and professional level [5, 19, 23, 24, 26]. Knowing that the GIRD and no GIRD groups are different from one another, it was then desired to see if there was any significant association between the two groups and the two history groups: injury history and no injury history. The chi-square test revealed that there is no significant association between the deficit groups (GIRD and no GIRD) to the history groups, p-value = 0.434. Therefore, there is no significant association between injury history and the presence of GIRD.

Additionally, the Pearson correlation test revealed a statistically significant correlation of internal rotation EPA between the throwing and nonthrowing shoulders. This indicates that there could be a relationship between the two shoulders. Given that pitchers are likely to stretch both shoulders during warm ups, it is not unsurprising that there is a positive correlation between the two shoulders.

It is important to keep in mind that the pitchers were all healthy during testing. The fact that there is no significant association between injury history and the presence of GIRD indicates that once pitchers are healthy again, their shoulder rotational properties return to normal. Therefore, it is possible to use the bilateral difference of internal rotation EPA as a metric for return to play. Following injury, once shoulder rotational properties return to the normal values, these pitchers are indistinguishable from their no injury history counterparts.

5.3 Injury History as Related to TRM Deficit

Objectives 3 and 4 were used to address the second hypothesis that there is no relationship between injury history and the presence of TRM deficit. The third objective was to determine the prevalence of TRM deficit at the collegiate level. Ellenbecker et al. found that there are no statistical bilateral differences in TRM at the professional level [24]. However, the results of this study show that over half of the collegiate pitchers have a bilateral TRM deficit of at least 2°, and that roughly half of pitchers meet the criteria for TRM deficit (at least 5° bilateral deficit). The TRM measured by Ellenbecker was around 145° for the throwing and nonthrowing arm [24]. It is well established in literature that the actual values for these rotational properties vary greatly [30]. This can be seen in Table 2.2. One major reason for this is the of method of measurement used to determine range of motion. By utilizing a custom sensor that is validated and repeatable, some of the disparity in determining 'end-feel' has been eliminated. Therefore, our results indicate that while TRM is similar for the throwing (209.96°) and nonthrowing (211.36°) arms, TRM deficit is still present at the collegiate level.

The fourth objective was to determine if there was any association between injury history and the presence of TRM deficit. In order to accomplish this, it was first demonstrated that the shoulder rotational properties of the TRM deficit and no TRM deficit groups were statistically different from one another. For the throwing shoulder, the median TRM for the TRM deficit group (205.2°) was significantly lower than the no TRM deficit group (213.6°), $p\text{-value} < 0.001$. Additionally, the median internal rotation EPA of the nonthrowing shoulder for the TRM deficit group (219.5°) was significantly higher than the no TRM deficit group (204.9°), $p\text{-value} < 0.001$. Knowing that the TRM deficit and no TRM deficit groups are different from one another, it was then desired to see if there was any significant association between the two groups and the two history groups: injury history and no injury history. The chi-square test revealed that there was no significant association between the deficit groups (TRM deficit and no TRM deficit) to the injury history groups, p-value = 0.533. Therefore, there is no significant association between injury history and the presence of TRM deficit.

Additionally, the Pearson correlation test revealed a statistically significant correlation of TRM between the throwing and nonthrowing shoulders. This indicates that could be a relationship between the two shoulders. Given that pitchers are likely to stretch both shoulders during warm ups, it is not unsurprising that there is a positive correlation between the two shoulders.

It is important to keep in mind that the pitchers were all healthy during testing. The fact that there is no significant association between injury history and the presence of TRM deficit indicates that once pitchers are healthy again, their shoulder rotational properties return to normal. Utilizing this method, it is possible to use shoulder rotational properties as a metric for return to play. Following injury, once shoulder rotational properties return to the normal values, these pitchers are indistinguishable from their no injury history counterparts.

5.4 Injury History as Related to Pathological GIRD

The fifth objective of this study was to determine the impact that injury history has on the presence of pathological GIRD at the collegiate level. In order to accomplish this, the sample of pitchers were divided into four exclusive groups: pathological GIRD, anatomical GIRD only, TRM deficit only, and neither deficit. Kruskal-Wallis tests were conducted to establish that there were significant differences in internal rotation EPA and TRM for both the throwing and nonthrowing shoulders. There were significant differences between the majority of the deficit groups, but the GIRD only group had no significant differences to any other groups. This is most likely due to the small sample size of the GIRD only group.

The chi-square analysis showed that there were no statistically significant associations between the four exclusive deficit groups and the no injury history and the injury history groups. This indicates that regardless of whether the pitchers had an injury history or not, they were equally likely to fall into any of the deficit groups. Therefore, once a pitcher is fully healed following injury, their shoulder rotational properties should be similar to those pre-injury or compare to those of an average healthy baseball pitcher.

5.5 Injury History as Related to E/I Ratio

The final objective of this study was to determine the impact that injury history has on the E/I ratio of collegiate baseball pitchers. The E/I ratio of pitchers who had an injury history was compared to those who had not, and there was no statistical difference between the two (p-value = 0.867). The mean E/I ratio for pitchers who have had no recent injury was 1.97 ± 0.44. Therefore, pitchers were considered to have a high E/I ratio if their E/I ratio was greater than one standard deviation above the mean, or greater than roughly 2.4. The Pearson chi-square test showed that there was a statistically significant association between a high ratio and whether that pitcher had a recent injury. Surprisingly, it showed that pitchers who had a high E/I ratio were more likely to fall into the no injury history group. This could indicate increased external rotation and decreased internal rotation, which would increase the E/I ratio, might protect the pitcher from some injuries.

Additionally, a combination of a high E/I ratio and other deficits such as GIRD, TRM deficit, and pathological GIRD were analyzed as well. It was reported that there were no statistical associations between a combination of a high E/I ratio and any other deficit with injury history. This could be in part due to the smaller sample of pitchers who fell into these categories.

The Pearson correlation test that compared bilateral internal rotation EPA and E/I Ratio also had a significant correlation. Therefore, this indicates that the proposed ratio has a correlation with GIRD. It appears that pitchers with higher degrees of GIRD also have increased E/I Ratios.

The Pearson correlation test that compared bilateral TRM and E/I Ratio also had a significant correlation. Therefore, this indicates that the proposed ratio has a correlation with TRM deficit. It appears that pitchers with higher degrees of TRM deficit also have increased E/I Ratios.

5.6 Application of Findings

One aspect of this study was to determine whether shoulder rotational properties, such as GIRD, TRM deficit, or E/I ratio can be used as an objective metric for return-to-play criteria. The findings of this study show that there are no significant differences between the players who had a past injury to those have not in regards to the occurrence of GIRD, TRM deficit, or pathological GIRD. However, there was a significant association between E/I ratio and injury history. This association showed that pitchers with a high E/I ratio were actually more likely to fall into the no injury history group. As discussed in Section 4.7 when analyzing a few pitchers specifically, there seems to be potential to use GIRD, TRM deficit, and E/I ratio together to determine whether pitchers are at a healthy enough level to return to play.

5.7 Limitations:

As with any scientific study, there are always limitations. One limitation of this study was the sample size in some of the deficit groups (i.e. the GIRD only group having a sample size of only 7). In order to account for this, the collective GIRD group (all pitchers who had anatomical GIRD) were analyzed in Section 4.2 and discussed in Section 5.2 to ensure that the sample size did not affect any results.

Another limitation of this study was the non-normal distributions of the shoulder rotational properties. There were a handful of samples that could have been considered outliers by objective metrics, such as the interquartile range method. However, it was decided that it would be best to include all samples to gain additional knowledge of the sample as opposed to excluding them in hopes of obtaining normal distributions. To address this topic further, parametric analysis such as independent-samples t-tests, paired-samples t-tests, and one-way ANOVA were used to compare to the non-parametric statistical methods used and the same results were found.

A further limitation of this study is that it has been shown that the shoulder rotational properties of pitchers alter with time [34]. Freehill et al. determined that the external rotation and total range of motion of a pitcher increase significantly after a single episode of starting pitching and changes to external rotation, internal rotation, and total rotational motion occurred over a full season [34]. It was not determined prior to testing when the last time that a pitcher had thrown competitively. Therefore, the shoulder rotational properties might be altered depending on the time between throwing and when the test occurred.

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

Injuries among overhead throwing athletes, such as baseball pitchers, are incredibly common due to the repetitive, high demand that the joint experiences. In order to reduce the risk of injuries, shoulder rotational properties have been studied. This study focused on those same properties to see whether those properties are altered after injury once the pitchers are healthy again. Additionally, this study investigated whether pitchers with injury history are more likely to experience GIRD, TRM deficit, or have a high E/I ratio once they are healthy again.

6.1 Injury History as Related to GIRD

The first two objectives of study aimed to determine the prevalence of GIRD at the collegiate level and whether there was any association between injury history and the presence of GIRD. This study has added to the findings in literature that GIRD is present for pitchers at the collegiate level. Additionally, pitchers with an injury history had no association with the presence of GIRD. Therefore, once pitchers have recovered from their injury, their shoulder rotational properties also return to those of a common, healthy pitcher. This is why it is believed that analyzing shoulder rotational properties can be used a return-to-play metric for collegiate pitchers. It appears that once the shoulder rotational properties match those of the pre-injury/pre-surgery status, the pitcher is healthy and has similar properties to those of other healthy collegiate pitchers.

6.2 Injury History as Related to TRM Deficit

Objectives 3 and 4 of this study were focused on the prevalence of TRM deficit at the collegiate level and whether there was any association between injury history and the presence of TRM deficit. This study determined there were significant difference in TRM between the throwing and nonthrowing shoulder at the collegiate level. Therefore, TRM deficit was found in roughly half of the pitchers. However, pitchers with an injury history are not a higher risk of developing a TRM deficit. Once again, it appears that analyzing the shoulder rotational properties of a pitcher yield useful information of whether they are ready to return to play.

6.3 Injury History as Related to Pathological GIRD

Another objective of this study was to determine what pathologic GIRD, a combination of anatomical GIRD and TRM deficit, looked like for a collegiate pitcher. This study revealed that pitchers with an injury history had no significant association to pathological GIRD, anatomical GIRD, TRM deficit, or no deficits. Therefore, this objective adds evidence to the case that analyzing shoulder rotational properties can be a useful metric to determine whether pitchers are ready to return to play following an injury.

6.4 Injury History as Related to E/I Ratio

The last objective was to study the impact of the new E/I ratio variable. It was determined that this ratio is correlated with both GIRD and TRM deficit. It was also discovered that pitchers with a high E/I ratio were less likely to have a recent injury. There is some evidence that E/I ratio can be used in tandem with GIRD and TRM deficit as return to play metrics. However, much more research can be done to determine the impact that this new variable can have.

6.5 Future Work

This thesis analyzed part of a larger MLB sponsored project and much useful data can be analyzed for future projects. The scope of this project focused on injury history in relation to specific shoulder rotational properties and bilateral deficits, such as GIRD, TRM deficit, and pathological GIRD. Additionally, this thesis introduced a new variable, the E/I Ratio. It would be useful to analyze the injury data at the one-year follow-up and beyond to determine how these variables can be used as risk factors as opposed to return-to-play metrics. It is the belief of these authors that more research can be done on the E/I Ratio. With additional studies, there could a result a situation where the E/I Ratio is used in tandem with GIRD and TRM deficit to identify potential risk for baseball pitchers.

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