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Humeral Retrotorsion in Developing Children and its Relationship to Throwing Sports

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to Throwing Sports

by

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Approval/Signature Page

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Abstract

Humeral Retrotorsion in Developing Children and its Relationship to Throwing Sports

Background: Baseball players exhibit a more posteriorly oriented humeral head or humeral retrotorsion (HRT) in the dominant arm, likely representing an adaptive response to the stress of throwing. This adaptation is thought to occur while skeletally immature, however there is limited research detailing how throwing while young influences the development of HRT. In addition, it is currently unclear how this changing osseous orientation influences shoulder motion within young athletes. **Purpose:** To determine the influence of throwing and age on the development of asymmetry in HRT and shoulder range of motion (ROM), and analyze the relationship between HRT and ROM. **Study Design:** Cross-sectional age matched study. **Methods:** Healthy athletes (8-14 years-old) were categorized into two groups based upon sports participation; throwing group (n=85) and non-throwing group (n=68). Bilateral measurements of HRT, shoulder external (ER), internal rotation (IR) and total range of motion (TROM) were performed using diagnostic ultrasound and digital inclinometer. A two-way analysis of variance was performed with throwing status (yes/no) and age group (youth (8-10.5), junior (10.51-12) and senior (12.01-13.99)) as primary factors**.** Dependent variables were asymmetry (dominant-non-dominant) in HRT, ER, IR and TROM. The relationship between ROM and HRT was analyzed using Pearson correlation coefficients. **Results:** Throwing athletes demonstrated a larger degree of HRT on the dominant side, resulting in greater asymmetry (8.7° versus 4.6°). Throwing athletes demonstrated a gain of ER (5.2°), a loss of IR (6.0°) and no change in TROM when compared to the non-dominant shoulder. Pairwise comparisons identified altered HRT and shoulder ROM in all age groups of throwers. A significant but weak relationship between HRT and shoulder ROM existed. **Conclusion**: Throwing causes adaptive changes in HRT and shoulder ROM in youth baseball players at a very young age. Other factors in addition to HRT influence shoulder motion within this population. **Clinical Relevance:** In baseball players, an altered arc of motion can be expected at a young age. This adaptation is in part due to changes in osseous structures, however a larger component of change is likely due to other factors.

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CHAPTER 1: INTRODUCTION

BACKGROUND

Baseball is one of the most popular sports amongst children in the United States with over 2 million participants age 4-18 competing in Little League Baseball in 2012.[1] Although baseball is an inherently safe sport, injuries do occur. In a cohort of baseball pitchers aged 9 to 14 years, Lyman et al[2] noted that 32% complained of shoulder pain and 26% complained of elbow pain at some point during the season. Similarly, in a study by Trakis et al[3] it was found that 52% of a group of adolescent pitchers experienced throwing related pain during the competitive baseball season. Recent trends have indicated that these young athletes are sustaining upper extremity overuse injuries with increasing frequency.[4,5] This chapter will provide a brief overview of some of the predisposing factors related to upper extremity injury within this young group of athletes, and outline a proposed research study in order to improve our understanding of injury dynamics within this population.

STATEMENT OF PROBLEM AND GOAL TO BE ACHIEVED

Several modifiable risk factors have been identified that may predispose an athlete to developing an overuse injury, including pitching with arm fatigue, pitching with pain, playing baseball more than 8 months each year, high overall volume of pitching per game or season, throwing breaking pitches at a young age, and inadequate rest between pitching outings.[4-8] In addition, intrinsic factors related to muscular performance, shoulder range of motion, pitching mechanics, and kinetic chain dysfunction have been linked to the development of overuse injuries within the youth and adult baseball populations.[9] Modifiable risk factors represent an important characteristic for sports rehabilitation professionals, as interventions geared toward addressing these issues can serve to prevent injury.

Several studies have consistently shown that athletes involved in unilateral throwing sports exhibit a pattern of increased dominant shoulder glenohumeral external rotation (GER) and limited glenohumeral internal rotation (GIR) when compared to the non-dominant side.[9-13] This characteristic alteration in glenohumeral (GH) motion has been attributed to adaptive changes that occur as a result of repetitive microtrauma due to the high degree of rotational torque placed across the shoulder during the throwing motion.[14,15] Although considered to be a normal adaptive change, an abnormal degree or magnitude of altered shoulder motion has been consistently associated with shoulder or elbow injuries in throwing athletes.[9] Specific changes that may contribute to this altered arc of motion include anterior capsule stretching, posterior capsule or tissue tightness and increased humeral retrotorsion.[9-11,16,17]

Humeral torsion is defined as the angular difference in the relative positions of the humeral head and the axis of the elbow at the distal humerus.[18,19] Humeral retrotorsion (or retrotorsion) describes the bony architecture that occurs when the head of the humerus is oriented in a posterior direction which is associated with transverse plane rotation within the humerus. Several studies have investigated side-to-side differences in humeral retrotorsion in throwing athletes, and have determined that there is a consistent finding of increased humeral retrotorsion in the dominant shoulder within this population.[10,20-26] It has been proposed that the bony adaptations responsible for this are likely to occur in the pediatric or adolescent years, and are related to the volume of throwing activity performed.[1,10,13,26-28] However, these factors have not been thoroughly investigated within this young population.

Due to the integrative relationship bony architecture will have on joint mechanics, one would anticipate increased humeral retrotorsion to shift the arc of motion in the shoulder to favor increased GER and decreased GIR. Several investigators have sought out to determine if this holds true. In general, studies have identified a consistent relationship between increased humeral retrotorsion and increased GER, however, the relationship between humeral retrotorsion and GIR is less clear.[19] The inconsistency in correlation of humeral retrotorsion with loss of shoulder internal rotation may be explained by the findings that throwing produces changes in the posterior capsule that may lead to a loss of shoulder internal rotation.[29] Due to the effect of humeral retrotorsion on GH range of motion (ROM), and the understanding that deficits in shoulder rotational ROM are implicated as a risk factor for shoulder or elbow injuries in throwing athletes,[9] it is important to further evaluate the process by which humeral retrotorsion develops within the throwing athlete, and further investigate the effects of altered humeral orientation on shoulder rotational ROM.

The primary goal of the proposed research study is to investigate alterations in humeral retrotorsion relative to age and throwing volumes. Briefly, we will accomplish this by comparing the degree of humeral retrotorsion between two groups of pediatric athletes (ages 8-14): one group that participates heavily in baseball and another group of similarly athletic, age matched, non-throwing individuals. In addition, we will seek to further clarify the relationship between humeral orientation and GH ROM by determining the correlation between shoulder rotational ROM and humeral retrotorsion in both the throwing and non-throwing groups.

Research Question and Hypothesis

Adult throwing athletes demonstrate an altered arc of dominant arm GH joint ROM. It is likely that this side-to-side motion asymmetry is the result of bony and soft tissue adaptations caused by the stress of the throwing motion. It has been proposed that the bony adaptations are likely to occur in the pediatric or adolescent years and are related to the volume of throwing activity performed; however, these factors have not been thoroughly investigated within a young sample. The primary purpose of this study is to investigate humeral retrotorsion across an age spectrum (8-14) of young athletes with different throwing histories.

Specific Aim 1:

Determine the effects of throwing activity and age on humeral torsion and glenohumeral ROM by comparing young throwing athletes to non-throwing athletes across ages 8-14. To address this aim we plan to utilize diagnostic ultrasound to measure and compare humeral torsion and glenohumeral ROM in 60 throwing athletes between 8-14 years of age with a matched group of 60 non-throwing athletes.

Hypothesis 1a: Throwing athletes will have a larger between-side difference in humeral torsion and glenohumeral ROM than non-throwing athletes.

Hypothesis 1b: As age increases, throwing athletes will demonstrate a larger between-side difference in humeral retrotorsion and glenohumeral ROM than non-throwing athletes (interaction effect), reflecting the pattern of less internal rotation and greater external rotation in the dominant shoulder.

<u>Specific Aim 2</u>:

To determine the relationship between <u>humeral torsion</u> and glenohumeral <u>range of motion</u>. To address this aim we plan to study 120 young athletes (throwers and non-throwers) between 8-14 years of age and assess the correlation of humeral orientation and glenohumeral ROM within individuals.

***Hypothesis 2**:* Shoulder ROM is expected to correlate with humeral retrotorsion. However, we believe that soft tissue changes that occur during the developmental process will also influence shoulder range of motion. Therefore we hypothesize the correlation between humeral torsion and rotational range of motion will only be moderate (0.3-0.4). We also hypothesize that the correlation will be weaker in throwers than non-throwers because of greater soft-tissue effects in throwers.

Relevance and Significance

Several research studies have documented a pattern of increased GER and decreased GIR in the dominant arm of throwing athletes.[9-11] While several factors related to soft tissue and bony alterations may account for such a finding, the relative degree of influence of each remains unknown. Several authors have noted consistent findings of increased humeral retrotorsion within the dominant shoulder of specialized throwing athletes.[10,20-26] Due to the relationship of bony geometry and ROM, this finding is consistent with the observed shift in shoulder ROM favoring ER. It has been proposed that these bony changes are likely to occur prior to skeletal maturity and may serve a protective role against overuse injuries to the shoulder.[9,28,30,31] During normal growth and development, the proximal humerus undergoes a process of derotation, such that it rotates from a higher degree of retrotorsion to a position of less humeral retrotorsion.[18,32,33] It is theorized that the stress imparted to the humerus during the throwing motion slows this natural process of derotation and yields an end result of increased retrotorsion in the dominant shoulder of throwing athletes.[28,30] A few studies have assessed these adaptive changes in the youth throwing athlete; however, several crucial aspects such as the age of onset of these changes, the correlation of bony changes to alterations in shoulder ROM, the relative degree of bony versus soft tissue adaptation, and the degree of progression have not been clearly established.[10,31,34] Identifying an age-dependent relationship of these adaptive changes may enhance our understanding of upper extremity injury dynamics and enable the development of improved injury prevention strategies. The proposed study will seek to provide information on the process by which humeral torsion asymmetry develops, and on how alterations in the proximal humerus affect available shoulder range of motion.

In general, studies within adult populations have demonstrated a consistent relationship between increased humeral retrotorsion and gain in shoulder external rotation ROM, but this relationship has been less consistent for loss of internal rotation.[19] The inconsistency in correlation of humeral retrotorsion with shoulder internal rotation may be due to the findings that throwing produces changes in the posterior capsule that may lead to a loss of shoulder IR.[29] The effect that humeral retrotorsion has on the degree of available shoulder range of motion may play an important role in terms of likelihood of injury, as loss of shoulder internal rotational motion has been identified as a risk factor for injury among throwing athletes.[9] The results of this study will not only add to the body of literature examining the effects of humeral torsion on shoulder ROM, but will also examine the relative timing of changes in humeral torsion to alterations in shoulder motion. This study will seek to determine if a temporal relationship exists in which humeral torsion changes produce alterations in range of motion, or if a side to side difference in ROM exists in throwers prior to divergence of humeral torsion measurements. Examination of this sequencing is important because other studies have shown an altered arc of motion may exist in pediatric and adolescent baseball players,[3,31,35] but it is currently unknown what physiological mechanism is responsible. The addition of ultrasound assessment of humeral torsion into our study design will allow for determination of soft tissue versus bony effect on ROM in the developing athlete.

The proposed study design is unique in that we are including a control group of non-throwing athletes. This factor will assist in distinguishing between genetic factors and age or activity-dependent changes related to the humeral derotation process in youth athletes. Whiteley et al[36] have proposed that there may be a genetic predisposition in which throwing athletes, who tend to have a higher baseline level of humeral retrotorsion, may be less susceptible to injury. The degree of retrotorsion present in the dominant shoulder is a result of two factors: 1) the degree of genetic retrotorsion and 2) the degree of acquired humeral retrotorsion influenced by throwing activity. Whiteley et al[36] proposed that those who genetically have greater retrotorsion and thus need to acquire less retrotorsion may be less prone to injury. Crockett et al[10] postulated that baseball players may have a *window of opportunity,* prior to skeletal maturity, to develop enough humeral retrotorsion to protect the shoulder and allow for elite level of playing with less potential for injury. Yamamoto et al[28] determined that pitchers who began pitching after the age of 11 had less humeral retrotorsion than those who began pitching prior to that. Their results are suggestive that 11 years of age may be a critical point for the necessity of throwing-induced proximal humeral changes for throwing athletes. The study design we propose would allow us to deepen our understanding of throwing-dependent changes in the bony anatomy of the proximal shoulder by comparing the natural changes associated with aging and those influenced by throwing. Additionally, our study design would allow for clarification regarding the timing of changes associated with throwing and determination if there is a *window of opportunity* for adaptation and what age is important. Ultimately, the results of our analysis could help determine how throwing volumes affect the youth throwing shoulder and potentially contribute to youth specific throwing injuries, such as Little League Shoulder or Little League Elbow.

DEFINITION OF TERMS

Humeral Torsion: Humeral Torsion is a general term describing a twisting that occurs about the long axis. It is specifically defined as the rotational difference in the relative position of the humeral head and the axis of the elbow at the distal humerus.[18,19]

Humeral Retrotorsion: Humeral retrotorsion refers to a specific orientation of humeral torsion in which the head of the humerus is oriented in a posterior medial direction and is associated with a transverse plane rotation within the humerus.

Glenohumeral Rotational Motion: Glenohumeral rotational motion is the normal degree of physiological rotational motion present within the shoulder. This is specifically applied within this study at 90° of shoulder abduction in the coronal plane. Shoulder external rotation and shoulder internal rotation are summed to determine total shoulder range of motion.

LIST OF ABBREVIATIONS

Glenohumeral	GH
Glenohumeral External Rotation	GER
External Rotation	ER
Glenohumeral Internal Rotation	GIR
Internal Rotation	IR
Range of Motion	ROM
Total Range of Motion	TROM
Ultrasound	US
Computed Tomography	CT
Magnetic Resonance Imaging	MRI
Humeral Retrotorsion	HRT
Glenohumeral Internal Rotation Difference	GIRD
Glenohumeral External Rotation Difference	GERD

SUMMARY

The dominant shoulder of throwing athletes exhibits activity dependent changes in bony morphology. It is currently not clear how early these changes begin to appear, what role these changes may play in the manifestation of upper extremity injury, and to what degree bony changes affect shoulder range of motion. The intention through the remainder of this document will be to add to the body of literature on this important topic and assist in improving our understanding of the developing throwing athlete.

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

This chapter will serve as a comprehensive review of the literature surrounding all aspects of this proposed research process. The initial section of this chapter will focus on detailing the normal developmental process of humeral torsion in humans. After describing this process, this chapter will explore normative values of humeral torsion in non-athletic populations and contrast those to the literature surrounding overhead athletes. Additionally, we will explore and analyze current literature on the relationship between humeral torsion and glenohumeral range of motion (ROM) and relationship to upper extremity injury. Finally, this chapter will end with a summary of findings and explanation of identifiable gaps in the literature that remain to be explored.

DEVELOPMENT OF HUMERAL TORSION

Humeral torsion describes the angular difference between the orientation of the axis of the proximal humeral head and the epicondylar axis at the distal humerus.[18,19] (Figure 2.1) Most of the literature surrounding the description and understanding of this bony orientation has been published in anatomical and anthropological journals. However, a recent increase in the number of publications in the field of sports medicine has been noted due to findings that the act of overhand throwing may influence the orientation of the humeral head.[10,20,26,27]

Figure 2.1. Line drawing illustrating humeral retrotorsion

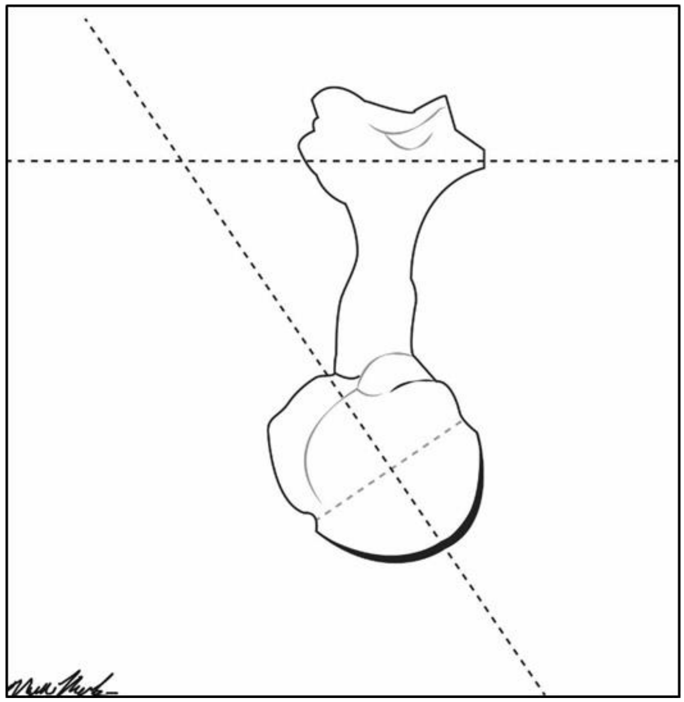


Figure 2.1. Schematic drawing of the left humerus, viewed from above. The dashed lines represent a line perpendicular to the proximal humeral articular surface (representing proximal humerus orientation) and the transepicondylar axis (representing distal humerus orientation). The difference between these angles is the degree of humeral retrotorsion present.

Currently, there is no consensus regarding the ultimate anatomical and/or functional factors that produce this torsional pattern.[37] However, most authors agree that the development of humeral torsion is likely a result of two factors: a primary torsion, stemming from a derotation process determined by developmental patterns of the embryo (similar to the derotation process that occurs in the proximal femur); and a secondary torsion, caused by rotational muscular forces acting on the growing humerus.[18,30,33,37,38] The mean humeral retrotorsion angle in humans has been reported to vary widely from a low of 3° to a high of 55°, however, most people tend to fall within the middle of this range, with the generally accepted value for adult retrotorsion being 25°-35°.[32,37,39] Although there is a large degree of variability, there are several factors that have been identified that may influence the general pattern of retrotorsion angle. As already discussed, habitual activity such as throwing or unilateral overhand sports has been found to induce a higher degree of humeral retrotorsion in the dominant limb.[10,20,21,23,25,27,28,40] When gender differences are examined, males often possess more retrotorsion than females,[18,32] and limb patterns generally demonstrate that the right humeral head is more retroverted as well.[18,41]

The majority of the early work related to the development of humeral torsion was done by Krahl,[18] who proposed that humeral torsion is a dynamic process that is related to the adaptive response of bone to the mechanical forces brought upon it, due in large part to muscular activity. Krahl[18] proposed that the proximal humerus undergoes a process of derotation in which the humeral head gradually moves from a more posteriorly oriented position, towards a more anterior-medially oriented position. Due to several factors, it has been suggested that the proximal humeral epiphysis is the site at which the torsion occurs. The humerus has two main growth centers, one at the proximal and another at the distal end of the bone. The proximal humeral physis contributes approximately 80% of the longitudinal growth of the humerus and usually fuses around the 19th to 22nd year of life.[18,42] The distal humeral epiphysis does not contribute as much to the overall growth of the humerus, and closes around the 14th or 15th year of life.[18] Krahl[18] and Edelson[33] have demonstrated that the humeral derotation process occurs early in life, with a rapid derotation occurring up to the age of 8, followed by a progressive slowing and eventually stopping around the age of 19 or 20.[18,32,33] This identified pattern of derotation supports the assumption of rotation occurring through the proximal physis due to the following: the derotation process does not seem to be affected by the earlier closure of the distal physis as derotation continues after closure of this growth center, and the cessation of the derotation process does correlate with the closure of the more active proximal physis.[18]

Additionally, Krahl[18] proposed that the arrangement of muscular forces about the proximal humeral physis can create an environment that causes a turning of the humeral head in respect to the shaft. In this model, the muscles that create rotational movement of the shoulder are the primary muscles of interest. The muscles can be grouped according to function. The medial rotators of the shoulder include the Pectoralis Major, Lattisimus Dorsi, Teres Major and the Subscapularis. The lateral rotators include the Supraspinatus, Infraspinatus and the Teres Minor. With the exception of the Subscapularis, the insertion point of the medial rotators is below the epiphyseal line, while the lateral rotators have an insertion that is above the epiphyseal line. (Figure 2.2 & 2.3) Due to this anatomical arrangement, the epiphyseal cartilage is located between muscles that create opposing forces, thus exerting a twisting or torsional force through the epiphyseal plate. When compared to cortical bone, this cartilaginous zone offers weak resistance to torsional forces, especially during periods of rapid growth. As a result, it would be more easily influenced to adaptively respond to the mechanical stress imparted to it by the function of these opposing muscle groups.[18,37] The influence of the torsional stress, imparted by medial rotators below the epiphyseal line and external rotators above the epiphyseal line, would tend to cause a medial rotation of the humeral head, with the point of torsion occurring through the proximal physis. The medial twisting of the humeral head would reduce the overall angular difference between the axis of the humeral head and the distal epicondylar axis, thus decreasing the total amount of humeral torsion. (Figure 2.4)

Figure 2.2. Insertion of main rotator muscles relative to the proximal humeral growth plate (anterior view)

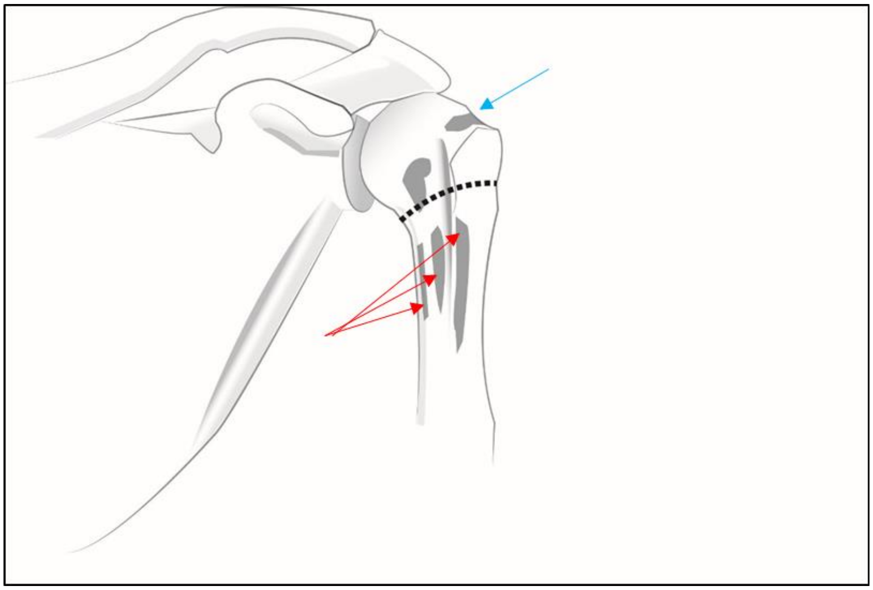


Figure 2.2. Anterior view of the proximal left humerus. Dashed line represents the location of the proximal humeral growth plate. Red arrows highlight insertion points of medial rotator muscles (Pectoralis Major, Lattisimus Major, Teres Major) inferior to the growth plate. Blue arrow represents insertion of lateral rotators superior to growth plate.

Figure 2.3. Insertion of main rotator muscles relative to the proximal humeral growth plate (posterior view)

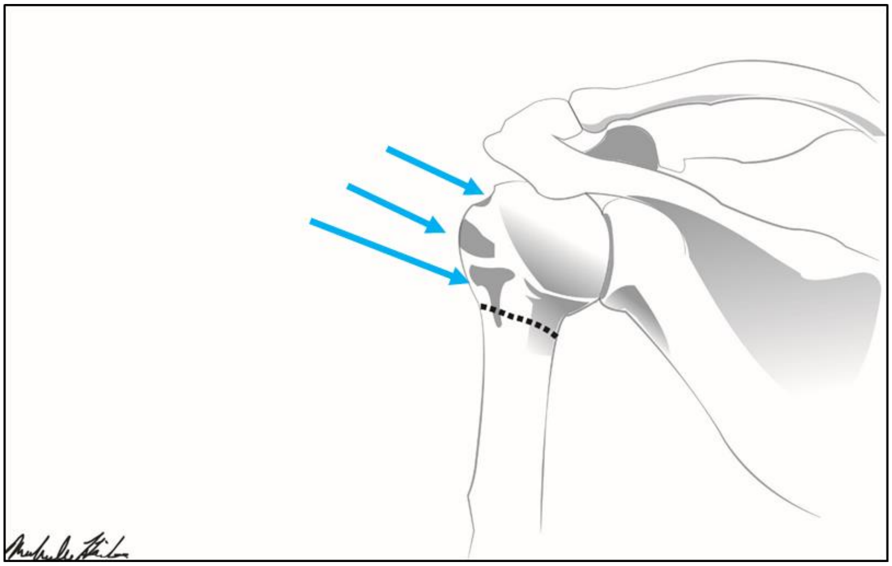


Figure 2.3. Posterior view of the proximal humerus. Dashed line represents the location of the proximal humeral growth plate. Blue arrows represent insertion of Supraspinatus, Infraspinatus and Teres Minor superior to growth plate.

Figure 2.4. Schematic representation of muscular forces producing proximal humeral derotation

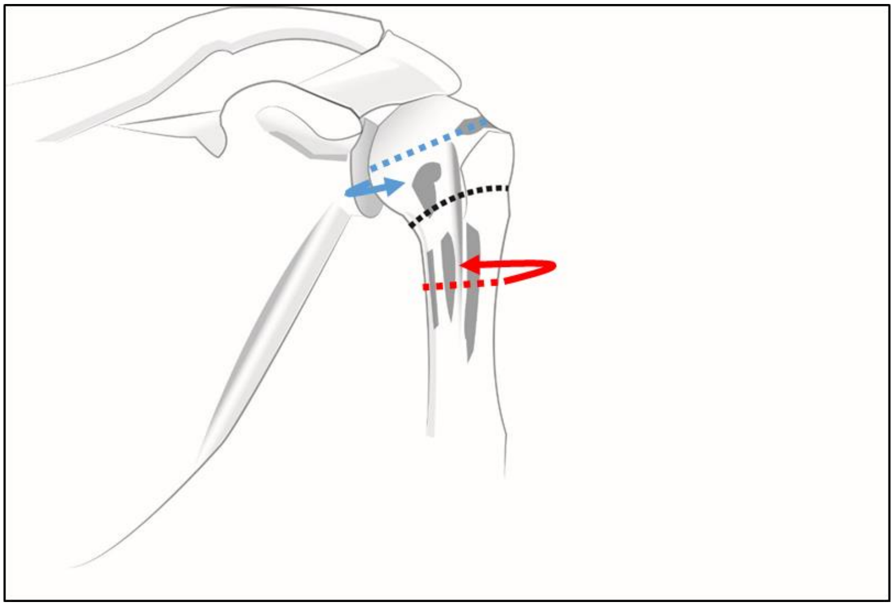


Figure 2.4. Anterior view of the proximal left humerus indicating the opposing rotational forces exerted by muscles above the physis (twisting humeral head externally) and below the physis (twisting shaft internally). These forces influence proximal humeral positioning during normal development. Assuming the humeral head begins in a higher degree of retrotorsion (more posteromedially oriented position) these forces would facilitate derotation resulting in a more anteriomedial

Despite this significant degree of evidence supporting the proximal humeral physis as the location of torsional change in the humerus, others have postulated that the adaptation could also occur within the diaphysis of the humerus.[21] Van Der Sluijs et al[43] performed a study on humeral retrotorsion in individuals with obstetric brachial plexus lesions. They determined that relative to the unaffected side, there was an increased degree of humeral retrotorsion in the affected limb. It is theorized that for normal development of the orientation of the humeral head, there is a requirement of balanced forces exerted upon the proximal humerus by both the medial and lateral rotators. The authors hypothesize that the birth related brachial plexus injury altered the dynamic relationship between the medial and lateral rotators in the shoulder and thus altered the normal derotation process that occurs with aging. Since the primary muscles affected by this type of injury are the external rotators (C5/C6 spinal nerves), it has been proposed that the unaffected and more powerful medial rotators would tend to exert a medial rotation force on the proximal humerus, causing a medially directed force through the shaft of the bone, resulting in a more posteriorly directed humeral head, relative to distal epicondylar axis.[37,43] Thus, by definition, this proposal requires that the entire proximal aspect of the humerus (above the medial rotator group insertion points) move as a unit, and the location of rotational change is within the shaft of the humerus and not within the proximal humeral growth plate.

The sports medicine literature lends some additional support to the humeral shaft as the location of bony adaptation. Investigators have found that the mid-shaft of the humerus, in the dominant arm of throwing athletes, demonstrates increased bone thickness[44] and adaptive changes which are suggestive of mid-humeral adaptation to torsional stresses (including increased total bone area, cortical area, cortical thickness and periosteal perimeter).[45] These results suggest that torsional forces introduced during throwing are of sufficient magnitude to induce bone remodeling. Thus, despite the majority of biomechanical and chronological evidence suggesting the derotation process occurs at the proximal humeral physis, the aforementioned studies do raise the possibility of bony changes in the diaphysis of the bone, and more importantly that these changes may occur post-skeletal maturity.

Currently, the exact forces or processes which are responsible for the eventual torsional orientation of the humerus remain largely unknown. It is the author's proposal that a specific range of applied forces are likely required in order to provide an environment conducive to normal developmental derotation and orientation of the humeral head. In the case of excessive stress (i.e. throwing) translated across the upper extremity, the normal developmental process may be disrupted resulting in an altered humeral torsion angle. Likewise, in the case of reduced upper extremity force translation (e.g. obstetric brachial plexus injury), the environment is not suitable for normal development of humeral orientation, creating an abnormal rotational profile.

MEASURING HUMERAL TORSION

Variability in Defining Measurement Expression

Simply stated, humeral torsion can be defined as the twisting of one end of the humerus in relation to the other. In order to fully present how the orientation of humerus is determined, it is necessary to make a distinction between how torsional angles are reported in different disciplines. As discussed earlier, much of the early work describing humeral orientation was carried out through the disciplines of anatomical study in evolutionary anthropology. Different assumptions regarding the definition of beginning orientation of the humeral head has led to a discord in measurement expression between evolutionary and clinical measurement of the same anatomical phenomenon.[46] Clinical or medical reports examine humeral torsion through the quantification of humeral retrotorsion (also known as retroversion), while evolutionary anthropologists quantify the humeral torsion angle. The primary difference between retrotorsion and humeral torsion relates to the assumption of the origin of the humeral head.[47] Evolutionary anthropology presumes the original position of the humeral head to be one in which the head is directed posteriorly, which would be necessary to articulate with the anterior facing glenoid fossa of a scapula that is positioned on the lateral aspect of the rib cage. In this convention, the humeral head is defined as being located at 0° and higher torsional values refer to a humeral head that is directed more medially.[18,47] In the clinical literature, the humeral head is defined as beginning facing directly medially accompanying a laterally facing glenoid fossa that came about as a result of the dorsal repositioning of the scapula during the evolutionary progression of humans.[47] In this convention, humeral retrotorsion describes a movement of the humeral head toward a more posterior facing orientation.

In summary, humeral retrotorsion assumes that the humeral head originates in a medial orientation and thus quantifies the extent of posterior twisting, while humeral torsion assumes the origin is posterior and refers to the amount of medial twisting.[46] While these two measures differ in defining constructs, it is important to understand that the two measurements are angular complements of one another. Thus, an increasing degree of humeral retrotorsion would reflect a decreased amount of humeral torsion and vice versa.[19,46,47] This variation in definition and language has led to a larger issue within the context of published literature, as there has historically been an inconsistency in terminology with humeral torsion and humeral retrotorsion being used interchangeably.[46] This has led to some issues with clarity in interpretation of results and comparing published data.

Figure 2.5. Illustration of humeral retrotorsion versus humeral torsion measurement reporting

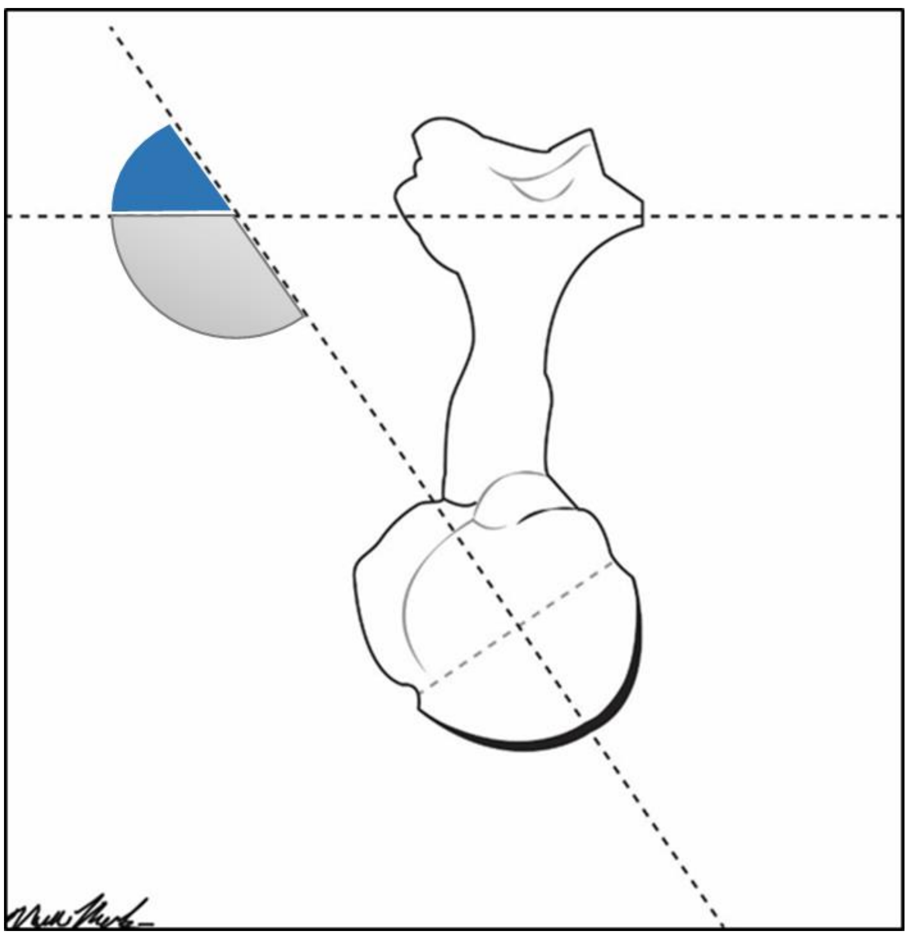


Figure 2.5. Schematic drawing illustrating differing angle report in terminology for humeral retrotorsion (blue) and humeral torsion (gray).

Methods of Quantifying Humeral Torsion

The earliest method of measuring humeral retrotorsion was through direct visualization of osseous anatomy. In a method originally described by Evans and Krahl,[48] determination of the long axis of the humerus is made and a line is drawn through the center of the humeral head, which intersects the axis at a right angle. At the distal end, a device called a torsiometer is used to assess the differences in axis location and determine the degree of humeral torsion. This method was further refined by Boileau et al[39] by utilizing a custom device that allowed for direct determination of the long axis of the humerus, thus limiting the potential for error inherent in the earlier method, which required subjective approximation of this axis. Although direct visualization and measurement of the osseous structure offers a high degree of precision, the requirement of cadaver specimens prevents the use of this measure in live subjects.

Alternative methods of measuring humeral torsion *in vivo* have been developed and include radiographic methods, computed tomography (CT), magnetic resonance (MR) imaging, and ultrasonography (US).

The reliability and validity of utilizing CT scan to assess humeral retrotorsion have been investigated, and historically CT measurement is considered to be the gold standard.[49] Due to a lack of standardized measurement techniques, there is some variability in the reporting of humeral torsion angles and reliability has been found to vary depending upon the bony landmark or measurement technique that is used. Hernigou et al[50] analyzed the accuracy of CT by comparing the measurement of humeral torsion utilizing two different standardized CT methodologies against direct visualization in a group of 10 fresh cadaver specimens. In this study the proximal reference line for the determination of humeral torsion was defined by a line perpendicular to the articular surface. The main source of error surrounding this aspect of measurement is due to the irregular geometry of the margins of the articular cartilage in the humeral head.[50] The nature of this variation means that the line reflecting the margins of cartilage may vary in a slice that depicts the center of the humeral head, compared to one depicting the distal part of the humeral head. Thus, it is important for the measurement to be consistently taken through the center point of the humeral head in order to ensure accuracy.

At the distal humerus, two methods of defining the distal axis were studied: 1) utilizing a transepicondylar line which was defined on a cross sectional image at the point at which the epicondyles appeared most prominent and 2) another using a line perpendicular to the long axis of the ulna. The second method was utilized in order to improve clinical understanding of how the ulna can be used to estimate humeral torsion. This was based on the observation that some surgeons use the forearm as a measure of retrotorsion during shoulder replacement surgery.[50]

In order to determine the reliability of CT for measurement of humeral torsion, three independent observers determined torsion angles at three different time points. A two-way random effect analysis of variance was used to determine the reliability of each measurement. The reliability coefficient (interclass correlation) was found to range from 0.65 to 0.90 with somewhat better reproducibility for the ulnar axis (0.89 to 0.90) than for the transepicondylar axis (0.85 to 0.89). In addition, Hernigeau analyzed the accuracy of this measurement based upon the level of the humeral head at which the proximal axis was determined. It was found that the reproducibility of this measure was better on sections passing through the distal part of the humeral head (0.87 to 0.90) than it was for those sections that passed through the center of the humeral head (0.77 to 0.82) or through the proximal head (0.65 to 0.76).

Due to the irregular shape of boundaries of the articular surface of the humeral head in cross sectional CT images, the degree of difference in measured retrotorsion based upon image slice depth was analyzed.[50] It was determined that the largest degree of variation was only 1.8°, and this value was not significant when subjected to a Mann-Whitney U test. Thus, at least for this specimen sample, it can be concluded that retrotorsion measured using a section passing through the distal part of the humerus is not different than measurement through the center of the humeral head.

Validity was determined by comparing humeral retrotorsion angle measured by CT against that directly measured on specimens utilizing regression analysis. The analysis showed a strong linear relationship between retrotorsion measured with CT and direct anatomical measurement ($r = 0.998$).

Cassagnaud et al[51] also examined the reliability of CT measurement of humeral retrotorsion in a group of 32 healthy individuals (64 shoulders) using 4 different raters of different experience levels. Intraobserver reliability was analyzed by Fermanian's Test, extracting a coefficient of reliability of the measurement RO. They found good to very good RO values for intraobserver reliability in both the dominant and non-dominant shoulders ranging from 0.77 – 0.96. Interrater reliability was analyzed using the Fleiss Method, which uses the Pearson correlation coefficient to assess the existence of a difference between the measurements of the observers, compared two on two. Results demonstrated less desirable reliability with Pearson's r-values of 0.73-0.84 in the non-dominant and dominant shoulders respectively.

Although CT is recognized to be the most accurate method of assessment, drawbacks such as high degree of radiation exposure, limited availability and cost may make it less attractive for routine use. Radiographic methods may offer the benefit of direct imaging with less radiation exposure and therefore improved clinical utility. Several radiographic methods have been described utilizing either two perpendicular projections in the antero-posterior and the semi-axial view,[20,38,52] or a single semi-axial view.[53]

Söderlund et al[53] advocated that the more simplistic semi-axial technique of determining humeral retrotorsion using radiography offered enough detail for accuracy in measurement while minimizing radiation exposure. Assessment of reliability and accuracy of this radiographic method was performed validating the measurement taken via radiography against CT. When compared to CT, radiographic measurement of retrotorsion angle showed a mean difference of 1.5° and the coefficient of variation was 2.3%.[53] The maximum difference in retrotorsion angle was only 2°. Inter and intrarater reliabilities were studied using the coefficient of variance between two different raters. The variation coefficient for intrarater reliability was better for the more experienced radiologists (2.8%) compared to the less experienced (6.4%). Interrater coefficient of variation was similar to intra at 4.6% with a mean angular difference of 1.0°. The authors concluded that although CT is the most accurate method of humeral retrotorsion assessment, a simple radiographic method may be more acceptable for routine clinical use, offering the advantage of accuracy with decreased patient radiation exposure.[53]

Boileau et al[39] further examined these various methods of assessment by comparing humeral retrotorsion measurements taken by direct computer-assisted visualization, CT, and standard radiographs in the same sample of 65 cadaveric humeri. They used a one-way analysis of variance (ANOVA) to compare the measurements obtained by radiographic and CT methods with those obtained by computer assisted measurement. It was determined that the radiographic method overestimated the humeral head retrotorsion ($p=0.046$, mean difference of 6.1°), however there was no difference ($p > 0.05$) between CT and computer assisted methodologies. These results are consistent with those of previous authors in concluding that the CT method appears to be superior to radiographic methods for the evaluation of humeral head retrotorsion in clinical applications.[39,50]

Recent advances in diagnostic ultrasound (US) technology have made this an attractive alternative to radiological measures. Ultrasound is being used with increasing frequency for musculoskeletal assessment because it offers convenience and accuracy in assessment of many conditions, while not exposing the patient to harmful radiation. Unlike the radiographic measures outlined earlier which measure torsion angles directly, US techniques offer an indirect measure of humeral torsion by calculating forearm inclination relative to standardized humeral position.[21,49,54] The underlying assumption in this technique is that forearm inclination is directly related to the distal humeral axis. For this technique, the subject is lying supine and positioned in 90° of shoulder abduction and 90° of elbow flexion. The ultrasound transducer is aligned level with the horizontal plane and perpendicular to the long axis of the humerus in the frontal plane.[49] Utilizing the US device, the bicipital groove is visualized, and the shoulder is either internally or externally rotated so that a line connecting the apexes of the greater and lesser tubercles is aligned with the horizontal plane on the screen. While maintaining this position on screen, the angle of the forearm is assessed using an inclinometer placed against the ulna. This angle represents the degree of humeral torsion. Using the angle of the forearm to reflect the relationship of humeral torsion is possible because the ulna is perpendicular to the epicondylar axis at the distal humerus. The forearm inclination angle measured at the ulna thus represents the angular difference between the epicondylar axis (distal humerus) and the horizontal line at the bicipital groove at the proximal humerus, corresponding to the degree of torsion within the humerus.[49] This measurement method has demonstrated excellent intra and interrater reliability with intraclass correlation coefficients ranging from 0.94 to 0.98 and an average measurement error of 2.3°.[16,21]

Myers et al[49] performed a validation study comparing the measurement of humeral torsion obtained between the accepted gold standard of CT and US methods. They compared the findings of torsional measurements on 24 limbs using these methods and studied agreement through regression analysis. They determined that a strong positive relationship (R=.797) existed between the two measurements, and that the degree of error associated with measurement by US was actually lower than that of CT. They concluded that ultrasound is a viable alternative to CT to obtain accurate and reliable measures of humeral torsion, while offering the convenience of portability, efficiency, and no harmful effects of radiation exposure.

HUMERAL RETROTORSION IN THROWING ATHLETES

Mechanism of Development of Increased Retrotorsion in Throwing Athletes

Athletes who participate in unilateral throwing sports expose their dominant shoulder to high levels of rotational torque. Several studies have investigated side to side differences in humeral retrotorsion in throwing athletes, and have consistently found increases in humeral retrotorsion in the dominant shoulder within this population.[10,20-26] The result of these studies are summarized in Table 2.1. Although all studies show similar results when comparing humeral retrotorsion side to side, there is some variability in the severity of these differences, which likely reflects several confounding factors related to age of subjects, throwing history, throwing mechanics, genetic variation, and measurement differences. Studies investigating side-to-side differences in humeral retrotorsion in young athletes are more limited. These studies indicate that in young throwing athletes humeral retrotorsion tends to decrease with age, however it is currently not clear at what age a significant side-to-side asymmetry develops.[13,28] (Table 2.2) The limited data available does appear to suggest that pre-adolescence or early adolescence is likely a pivotal time in development of humeral asymmetry, but more research is required to fully understand this process.

Table 2.1. Summary table of humeral retrotorsion asymmetry amongst athletes in published literature

Author	Subjects	Measurement type	Side-to-Side Difference in Retrotorsion (mean)
Pieper[20]	51 Olympic Handball Players	Radiograph	9.4°
Crockett et al[10]	25 professional pitchers 25 nonthrowing adults	CT	17°
Reagan et al[27]	54 Collegiate Baseball Players	Radiograph	10.6°
Osbahr et al[26]	19 Collegiate Baseball Players	Radiograph	10.1°
Chant et al[23]	19 Baseball Players (professional and collegiate)	CT	10.6°
Thomas et al[29]	24 Collegiate Baseball Players	US	15.6°
Polster et al[24]	25 Professional Pitchers	CT	10.8°
Shanley et al[55]	33 Professional Pitchers	US	13°
Noonan et al[56]	222 Professional Pitchers	US	19.5° w/ GIRD[a] 12.3° w/out GIRD[a]
Adult Healthy Population			
Matsumura et al[57]	205 healthy adults	CT	3°

([a] Players grouped according to glenohumeral internal rotation deficit (GIRD) defined as >15° loss of internal rotation with concomitant loss of 10° total range of motion.)

Table 2.2. Summary table of humeral retrotorsion asymmetry in youth baseball athletes

Author	Age group	Side to Side difference in Humeral Retrotorsion (mean ± SD)
Yamamoto et al[28]	3rd & 4th Graders	5.3°
	5th Graders*	7.5°
	6th Graders	1.8°
	7th Graders	2.7°
	8th Graders	3.6°
Hibberd et al[13]	Youth (6-10 years, mean 8.3 years)*	7.5° ± 10.1
	Junior High (11-13 years, mean 11.9 years)*	10.7° ± 9.9
	Junior Varsity (14-16 years, mean 14.6)*	15.3° ± 11.1
	Varsity (16-18 years, mean 16.9)*	16.2° ± 11.4
Whiteley et al[36]	Adolescent (Mean 16.6 ± 0.6 years)*	11.2°

In accordance with Wolff's Law, bone growth may be influenced by mechanical forces arising from muscular forces or external stress.[58] Sabick et al[30] performed a biomechanical analysis of the forces acting on the proximal humerus during the pitching motion, and determined that the magnitude and direction of forces is consistent with the development of humeral retrotorsion. Near the end of the arm-cocking phase, just before maximum external rotation, muscular forces act to create an internal rotation torque at the proximal humerus, while the humerus and forearm are still externally rotating.[59] The result of these opposing torques (internal rotation at the proximal humerus and external rotation at the distal humerus) creates a net torque about the long axis of the humerus, consistent with the direction of humeral retrotorsion.[30] The authors theorized that the forces created through the pitching motion may be sufficient to delay the normal derotation process at the proximal humerus, and could account for the differences between dominant and non-dominant humeral retrotorsion seen in this population.

While biomechanical factors related to the performance of throwing clearly demonstrate a possible influential relationship to the development of increased dominant arm humeral retrotorsion, others have presented alternative explanations. Cowgill[37] proposes that it may not be the act of throwing that influences humeral retrotorsion, but the resulting muscular dominance patterns that result from repetitive throwing which influence humeral growth. Several studies have documented that throwing athletes demonstrate a difference in strength ratios between their dominant and non-dominant arms, with higher ratios of medial to lateral rotation strength on the dominant side.[60-63] It is proposed that the more powerful medial rotators will exert an unbalanced medial rotation torque upon the proximal shaft of the humerus, which over time causes a bony shift in which the proximal humerus is directed more posteriorly relative to the distal end of the bone. It is felt that in the balanced shoulder, the rotational influence of the medial rotators is negated by the opposing muscular force of the external rotator muscle groups. Cowgill asserts that it is not the activity of throwing per se that results in higher angles of humeral torsion, but rather all repetitive activities during growth that create a functional imbalance resulting in relatively more powerful muscles of medial rotation can produce this morphology.[37] This proposal is an adaptation of the work discussed earlier by Van Der Sluijs et al[43] who described a similar mechanism responsible for the finding of increased humeral retrotorsion in children with obstetric brachial plexus injuries. To review, due to the attachment site of the majority of the internal rotators distal to the proximal humeral physis (Pectoralis Major, Lattisimus Dorsi, Teres Major) this proposed mechanism of humeral retrotorsion development requires that the humeral orientation change occurs in the diaphysis of the bone. This theory presents a shift from that presented by Krahl[18] who argues quite effectively that the change in humeral head orientation occurs from a torsion at the proximal humeral physis. As there is currently no consensus regarding the exact location of bony adaptation for humeral retrotorsion, further exploration of this model of adaptation is warranted in future research studies.

Humeral Retrotorsion and Relationship to Shoulder Range of Motion

Glenohumeral (GH) rotation range of motion is an important consideration during the evaluation and treatment of throwing athletes. Several studies have shown that healthy adult throwing athletes exhibit a pattern of increased glenohumeral external rotation (GER) and limited glenohumeral internal rotation (GIR) when compared to the non-dominant side.[9-12] It has been suggested that increased humeral retrotorsion may account for this observation,[16,26,27] however, soft tissue adaptations, such as anterior capsular laxity or posterior shoulder tightness(capsular and musculotendinous)[64-66] may also play a role.

Several investigators have sought to determine how osseous torsional changes influence clinically-measured glenohumeral motion. (Table 2.3) Generally speaking, the correlations appear inconsistent and weak, indicating that the osseous influence on glenohumeral motion is variable. In addition, it is possible that humeral retrotorsion may affect shoulder ER and IR differently.[56] Chant and colleagues[23] evaluated the relationship between humeral retrotorsion measured by CT and passive glenohumeral ER and IR range of motion at 90° abduction in a group of 19 baseball players (mean age 23.4 years ± 1.4 years). They determined that greater humeral head retrotorsion was associated with greater external rotation and lesser internal rotation range of motion at the shoulder. The relationship was stronger for external rotation (r = 0.548, 95%CI = 0.330 to 0.764, P < .001) than for internal rotation (r = -0.417, 95%CI = -0.650 to -0.112, P < .001). Although these values were statistically significant, they were associated with wide confidence intervals, demonstrating that the degree of ROM accounted for by humeral retrotorsion within this study is highly variable and the analysis may be limited.

Table 2.3. Summary table of relationship between humeral retrotorsion and throwing shoulder glenohumeral range of motion in baseball players

Study	**Sample**	**Correlation between humeral retrotorsion and GER**	**Correlation between humeral retrotorsion and GIR**
Osbahr[26]	19 college	r= 0.86	r= 0.01
Reagan[27]	54 college[a]	r= 0.43	r= 0.40
Chant[23]	19 subjects; professional and college, mean age 23.4 years	r= 0.55	r= -0.42
Thomas[29]	24 college	r= 0.30	r= -0.47
Noonon[56]	222 professional pitchers[b]	r= -0.17	r= 0.48
Hibberd[13]	287 youth baseball players, age 6-18 years	Correlations not reported. Older youth had greater GIRD and humeral retrotorsion asymmetry. GIRD differences disappeared if GIR corrected for humeral retrotorsion. Total ROM not different across age groups.	

[a]These values represent the correlation between retrotorsion and humeral rotation motion using side-to-side differences in each rather than absolute values.
[b] Sign of correlation varies depending upon reporting of torsion or retrotorsion.

Other investigators have obtained similar results to those of Chant et al[23] showing a significant relationship between humeral retrotorsion and rotation shoulder range of motion. An investigation by Thomas et al[29] found significant correlations between humeral retrotorsion and glenohumeral ER (r = 0.295, P=.042) and IR (r = -0.472, P=.001) range of motion changes in a group of 24 healthy collegiate baseball players. There were no confidence intervals reported by the authors.

Most recently, Hibberd et al[13] studied the effects of age and humeral retrotorsion on shoulder ROM in a group of 287 youth athletes aged 6-18 years. They described a unique measurement of retrotorsion adjusted glenohumeral internal rotation deficit (GIRD), representing the amount of IR ROM available from the humeral retrotorsion position, which corresponds to anatomic neutral position of the humerus.[13,16] By definition, this would represent the amount of shoulder IR ROM available after the degree of humeral retrotorsion has been accounted for. The results of this investigation demonstrated a significant difference in the degree of GIRD ($F_{3,284}$ = 8.957; P< .001) between age groups, and a difference in humeral retrotorsion between limbs ($F_{3,284}$ = 9.688; P < .001) that increased across age groups. However, there were no significant differences observed in retrotorsion-adjusted GIRD ($F_{3,284}$ = 1.136; P = .335) between age groups. Additionally, there were no differences between age groups in total range of motion (TROM) defined as the sum of available IR + ER shoulder ROM. ($F_{3,284}$ = 1.214; P = .305). These results provide additional support for the assertion that there is a strong and direct influence of the degree of humeral retrotorsion on the amount of shoulder ROM present; and that bone modeling, rather than soft tissue changes, accounts for the representative ROM shift seen in overhead athletes.

The findings of the above studies are in contrast to other reports describing a less direct correlation between humeral retrotorsion and both external and internal rotation, suggesting a higher degree of soft tissue involvement in the expression of ROM alterations. Osbahr et al[26] evaluated humeral retrotorsion in a group of collegiate baseball pitchers (n=19) and determined that there was a significant correlation with external rotation (r=0.864, P < .001), but not with internal rotation (r=0.010, P = 0.97) in the dominant throwing shoulder. Reagan et al[27] studied the relationship of humeral retrotorsion and glenohumeral rotation in a group of 54 (25 pitchers, 29 position players) asymptomatic collegiate baseball players. They reported a statistically significant relationship between the amount of humeral retrotorsion and GER (r = 0.432, p = 0.001) and GIR (r = 0.403, p = 0.003) at 90° of abduction. However, when the players were grouped according to position, it was found that the relationship differed between pitchers and position players. Pitchers no longer demonstrated a significant correlation between humeral retrotorsion and GIR (r = 0.370, p = 0.069) but the positive correlation with GER was maintained (r = 0.456, p = 0.022). Position players did in fact maintain significant correlations for both IR and ER movements (r = 0.446, p = .015 and r = 0.375, p = .045) respectively. Due to the fact that pitchers perform a higher volume of throwing activity, these findings are suggestive of a dose-dependent relationship to throwing that influences soft tissue factors in a way that accounts for the observed limitations in shoulder IR ROM.

A recent study by Shanley et al[55] provided additional support for the assertion that soft tissue rather than bony changes influence shoulder IR ROM loss. A group of 33 professional pitchers were followed over a 2-year period with measurements taken during spring training. The investigators sought to examine shoulder ROM and humeral torsion and the relationship to GIRD (defined as a loss of 15° or greater of IR combined with a loss of 10° or greater of TROM) by collecting the following dependent measures: Shoulder IR and ER ROM, degree of shoulder horizontal adduction (a direct measure of posterior tissue tightness), and humeral retrotorsion using US. They found that shoulder ROM on the dominant side demonstrated a significant increase in ER (12° ± 8°, P = .02) and a decrease in IR (-8° ± 11°, P = .03) and horizontal adduction (-17° ± 14°, P = .001), while the nondominant side remained the same. Additionally, they found that horizontal adduction and IR were positively correlated (r = 0.56 and r = 0.30, P < .01) with humeral torsion, and those pitchers who presented with GIRD displayed greater posterior shoulder tightness with decreased HA (P = .01) and greater humeral retrotorsion (P = .05). These results suggest that alterations in shoulder ROM are likely due to soft tissue changes (rotator cuff or capsuloligamentous) within this population. Moreover, these results implicate the degree of humeral retrotorsion is major a factor responsible for the development of GIRD.

The findings of the above studies are indicative of a scheme in which the stress imparted to the shoulder by the throwing motion may cause an adaptive soft tissue response and limit shoulder internal rotation ROM. Biomechanical analysis of the throwing motion gives some insight to the possible underlying mechanism of posterior soft tissue changes. As discussed earlier, greater humeral retrotorsion allows an athlete to gain ER ROM, with a concomitant loss of IR. An increase in shoulder ER allows for greater acceleration during throwing and has been shown to increase ball velocity.[67] After ball release, the posterior rotator cuff and capsule are responsible to absorb the stress and decelerate the arm during the final phase of throwing.[68] The increase in force and ball velocity during the acceleration phase, in players with greater humeral retrotorsion, would lead to a subsequent increase in distraction forces during the deceleration phase, and place greater eccentric stress across the posterior structures of the shoulder.[29,55] The greater degree of stress is likely to cause tissue overload or damage and result in loss of tissue flexibility. This theory is supported by the work of Shanley et al[55] who found that pitchers with GIRD demonstrated increased posterior shoulder tightness; and by Thomas et al[29] who found an increase in posterior capsule thickness in throwers with greater degrees of humeral retrotorsion.

Although this biomechanical model has a high degree of face validity and some research to support it, others have found no association between alterations in shoulder IR relative to humeral torsion and have discounted the influence of soft tissue on this finding. Hibberd et al[13] concluded that age-related changes in humeral retrotorsion accounted for all changes in shoulder TROM across a group of youth and adolescent athletes (range 6-18 years). Oyama et al[69] measured humeral torsion and shoulder ROM in a group of high school baseball players (age range 14-17 years) over a 1-year period and determined that although humeral torsion angle did not change, shoulder IR ROM was decreased, thus implicating soft tissue as the responsible factor. As eluded to earlier, this finding of soft tissue restriction is reinforced by Shanley[55] and Thomas[29]; however, it is important to note that these studies were performed on professional and collegiate athletes, in whom the degree of humeral torsion was also unchanging. It is possible that during the developmental years, when connective tissue properties are physiologically different and while humeral torsion angles are changing, the expression of shoulder ROM may be affected differently than in adults. This model could explain the variation in results seen by various studies in different populations.

Humeral Retrotorsion and Injury

The significance of variations in the degree of humeral retrotorsion in the throwing arm of athletes and its relationship to injury has been debated in the literature. It has been hypothesized that increased humeral retrotorsion may play a contributory or a protective role in the development of upper extremity injuries in the overhead athlete.

As discussed earlier, humeral retrotorsion has a distinct influence on the degree of shoulder IR, ER and TROM. This factor is extremely important due to the findings of several investigators that decreased IR (known as GIRD) and deficits in TROM have been linked with shoulder or elbow injury in throwing athletes.[9,68,70,71] However, the literature has demonstrated that there is variability in the association of changes in shoulder ROM and humeral retrotorsion, and further research is needed to more clearly identify the effect of humeral torsion and/or soft tissue on shoulder ROM within this population.

Peiper[20] believed that increased humeral retrotorsion represented an adaptive response to the stress of the overhead throwing motion, and served a protective effect to the shoulder. In his study, Peiper[20] measured side-to-side differences in humeral retrotorsion in a group of 51 male European professional handball players, 13 of which had complaints of chronic shoulder pain. In the asymptomatic group, there was an average side-to-side difference of 14.4° (SD 5.95) with higher retrotorsion in the dominant shoulder. The chronic shoulder pain group did not exhibit this pattern, and actually demonstrated an average decrease of humeral retrotorsion of 5.2° (SD 8.93) in the throwing arm. The side-to-side differences between the chronic pain group and the asymptomatic group were compared using t-test and were statistically significant (P <

.01). Peiper[20] hypothesized that increased humeral retrotorsion allows for a gain in external rotation range of motion, with less stress being placed across the anterior capsuloligamentous stabilizing structures of the shoulder. It is possible that those players with decreased humeral retrotorsion will transfer more stress to the anterior stabilizing structures of the shoulder during the throwing motion, which may lead to excessive strain in the anterior stabilizing tissues and the eventual development of anterior shoulder instability and pain.

Although a higher degree of humeral retrotorsion may serve a stress-shielding function to the anterior shoulder structures, it may impart increased stress to the posterior shoulder tissues. As discussed earlier, due to the altered arc of motion favoring increased shoulder ER and decreased shoulder IR, the posterior shoulder capsule and posterior rotator cuff may undergo increased stress during the deceleration phase of the overhead throw.[9,29] Thomas et al[29] identified a positive correlation (r= 0.43, p=0.003) between posterior capsule thickness and humeral retrotorsion supporting this concept. This capsular thickening could contribute to a subsequent loss of GIR and eventually to shoulder pathology.[9] However, increased posterior capsule thickness also appears to increase glenohumeral joint stiffness, and may have a positive effect of enhanced joint stability during high velocity movement.[72]

Recently, Polster et al[24] sought to further clarify the relationship of humeral torsion to injury potential. They prospectively recruited a group of 25 major league baseball pitchers, measured humeral retrotorsion using CT, and collected injury data for 2 years. The authors hypothesized that increased humeral retrotorsion would allow the shoulder to achieve the same degree of external rotation range of motion, while imparting less of a twisting force to the long head of the biceps and supraspinatus tendons. The forces translated across these structures by a reduction in humeral retrotorsion could result in injury to the rotator cuff tendons or superior labrum via the peel back mechanism. In support of this theory, the authors found a tendency towards more severe upper extremity injuries among pitchers with lower degrees dominant humeral retrotorsion, and those with smaller side-to-side differences in retrotorsion. Through further exploratory analysis, the authors introduced the concept of a protective "sweet spot", in which moderate degrees of torsion may serve a protective role, but values outside of this range may not.

Whiteley et al[36] performed a prospective study on a group of 35 elite adolescent baseball players (mean 16.6 years-old, SD 0.8) in which they measured the degree of humeral torsion using US, and then followed these players for a period of 30 months identifying any throwing-related injuries. Injuries were defined as any throwing arm injury that caused missed practice or game, and were quantified in "days lost" as an indicator of severity. There were a total of 19 athletes who experienced an injury during this time, with a mean of 26.6 days lost per injury (median 7.0 days). Humeral torsion values were compared between the uninjured and injured player groups using a Student's t-test. The injured group had significantly less humeral retrotorsion ($p = .004$) in the non-dominant arm, however, there was no significant difference in the dominant arm ($p = 0.47$). Receiver Operating Characteristic (ROC) curves were constructed to determine the predictive value of humeral retrotorsion on injury. The amount of torsion in the non-dominant arm (0.679, 95% CI 0.502-0.857) and the average humeral torsion between both arms (0.692, 95% CI 0.512-0.873) were both significant predictors of injury occurrence. Stated more succinctly, the findings of this study suggest that the amount of humeral retrotorsion present on the non-dominant side was more closely associated with and predictive of injury within this group of athletes. As discussed earlier, the degree of humeral torsion present in adults is a result of two processes: a "primary" torsion which is genetically determined, and an activity related "secondary" torsion which is superimposed over the primary torsion.[18] Whiteley et al[36] proposed that the degree of humeral retrotorsion present in the non-dominant shoulder represents the genetic contribution to humeral retrotorsion. Likewise, they suggest the degree of retrotorsion present on the dominant side is representative of the genetic contribution plus the amount acquired through the adaptive response of the bone to the stress of throwing. They postulated that the less genetic retrotorsion available, the more likely that additional retrotorsion would develop through adaptive responses. Thus, those individuals with a greater need for osseous adaptations may have a greater chance of injury. Examining this hypothesis from another perspective, the results indicate that individuals who genetically have the right amount of humeral retrotorsion available may be less likely to be injured. These results lend more credibility to the "*sweet spot"* concept discussed earlier, and suggest that in order to serve a protective role against injury, the "genetic" contribution to humeral torsion may be more important than the amount acquired through activity.

It has been suggested that the kinetic chain functions to minimize injury and optimize performance during throwing in 2 ways: 1) minimizing loads at smaller, distal segments by increasing efficiency at larger, proximal segments; and 2) decreasing loads seen by tendons or ligaments by optimizing bony alignment.[73,74] Due to the integrative nature of the throwing motion, it is plausible that alterations in the throwing motion proximally could have injurious effects distally.[70,74] For example, the increased shoulder external rotation associated with increased humeral retrotorsion contributes to the extreme degree of external rotation achieved during the late cocking phase of pitching. The greater degree of maximum external rotation at the late-cocking phase of throwing has been associated with increased valgus torque at the elbow,[30,59] which has been linked to an increased risk of elbow injuries.[75] This theory was supported by the work of Myers et al[40] who studied differences in humeral retrotorsion between a group of collegiate baseball pitchers with a history of elbow injury (n=13) and uninjured pitchers (n=19). They determined that pitchers with a history of elbow pain exhibited approximately 7° greater side-to-side limb differences in humeral retrotorsion than those with no elbow injury history. This study utilized retrospective, self-report injury data, and therefore a cause and effect relationship cannot be established. However, these results along with biomechanical plausibility indicate a possible relationship between the degree of humeral retrotorsion and distal upper extremity injuries. These factors reinforce the need for further studies on variations in humeral retrotorsion and their effects on injury dynamics.

GAPS OR CONTROVERSIAL POINTS IN THE LITERATURE

Does Throwing Activity Really Effect the Development of Humeral Retrotorsion?

There is a large body of literature demonstrating that throwing athletes exhibit increased humeral retrotorsion in their dominant shoulder.[10,20,22,23,25-28,36] This retroverted position of the humerus likely occurs as a result of throwing activity during the early years of childhood, which limits the natural process of humeral derotation, creating the side-to-side asymmetry. Although many authors agree with this hypothesis, there is currently a lack of specific studies and clear evidence documenting the bony changes that occur throughout the developmental process of the pediatric throwing athlete. Yamamoto et al[28] studied humeral retrotorsion in a group of young throwers (n=66, mean age = 12 years, range 9-14) and found that humeral retrotorsion tended to decrease with age, however the side-to-side difference was only significant in a single group of 5th graders. The most comprehensive study to date is that by Hibberd et al,[13] who studied humeral retrotorsion in 6-18 year-old baseball players (n=287) and found that statistically significant differences existed for every age group. These results contrast somewhat to those of Yamamoto, although it is likely that the Yamamoto study had low power due to small sample sizes in each group. In spite of this, the findings of the Hibberd study bring up an important question regarding the effects of throwing in the development of humeral retrotorsion. Statistically significant side-to-side differences were already present in the youngest age group of throwers (mean age 8.3 ± 1.3). Without the presence of a control group, it is unclear whether or not this side-to-side difference represents a genetic variation in humeral torsion, or if this difference is in fact accounted for by throwing (adaptive vs developmental). It is clear that additional studies are necessary to determine the process by which humeral torsion asymmetry develops in throwing athletes.

What Location of the Bone Does the Adaptation Occur?

As discussed earlier, the ultimate torsional orientation of the humerus is dependent upon primary genetic factors and secondary factors related to muscular forces and adaptive bone responses. The literature supports two competing ideas regarding the geographic location in the bone where the twist occurs. The work by Krahl[18] supports the idea that torsion is created by twisting through the proximal humeral physis, while the work by Van Der Sluijs et al[43] supports an assertion that the point of rotation occurs through the diaphysis of the humerus. The location of bony adaptation is important relative to the likelihood of torsion changes in pre or post-pubertal populations, and warrants further exploration in the literature.

What are the Effects of Throwing Volume on Humeral Retrotorsion?

Currently, it is unknown how specific factors related to pitching volume affect the development of humeral retrotorsion in young throwers. Research has identified a link between higher volumes of throwing and alterations in shoulder ROM and strength.[76] Due to the close relationship between humeral retrotorsion and shoulder ROM, it can be hypothesized that there may be a correlation between the identified changes in ROM and changes in humeral torsion angles; however, this has not been identified in the literature.

Does the Effect of Humeral Retrotorsion on Shoulder ROM Vary with Age?

At the time of this review, two studies have directly evaluated changes in humeral torsion and shoulder ROM in pediatric / young adolescent throwers. These studies resulted in conflicting conclusions. Yamamoto et al[28] found a significant difference in side-to-side measures of humeral retrotorsion, but no differences in TROM within a group of throwers aged 9-14 years. The authors postulated that if humeral retrotorsion was responsible for the pattern of shoulder ROM, there would have been significant differences seen for both humeral retrotorsion and TROM differences. It was their conclusion that soft tissue factors must be responsible for altered ROM within this young age group. On the other hand, Hibberd et al[13] found retrotorsion-adjusted GIRD and differences in TROM did not vary with age between limbs in a group of young throwers aged 6-18 years. Hibberd's group concluded that age-related changes in shoulder ROM (and specifically GIRD) are attributed to humeral retrotorsion and not soft tissue tightness. These conflicting results warrant further exploration and analysis.

An important distinction must be drawn in terms of study populations. Several studies have demonstrated results more consistent results with higher accountability of soft tissue for the expression of ROM alterations in high school,[69] collegiate[26,27,29] and professional level throwing athletes.[55] It is possible that during the developmental years of skeletal immaturity, when connective tissue properties are physiologically different than adults, that the expression of shoulder ROM may be affected differently than in adults.

It is well understood that as age progresses there is a natural change in the physical properties of connective tissue that results in increased stiffness of muscles and tendons.[77] Meister et al[34] studied glenohumeral ROM changes in 294 baseball players aged 8-16 years. They found that there was a steady decline in shoulder TROM with aging, and more specifically they found that shoulder ER ROM decreased with age. They hypothesized that although humeral retrotorsion changes should cause an increase in shoulder ER ROM, the overall loss of shoulder TROM may be indicative of age-related collagen changes that occur with maturation, making the relationship of bony changes and ROM changes less distinct within this younger population.

This model of maturation-influenced changes in soft tissue properties, and the resultant effect on mechanical functioning, could possibly explain the variation in results seen by studies in different-aged populations. Further research is needed to clarify the effect of changes in humeral retrotorsion on shoulder ROM, and whether this effect is in fact variable based upon the age of an individual. Exploring this relationship is clinically relevant because the treatment for the same clinical finding (e.g. decreased shoulder IR ROM) may vary based upon age of the presenting athlete.

Do Changes in Humeral Torsion Precede Changes in Range of Motion?

Meister et al[34] identified that the peak changes of decreased dominant shoulder IR ROM occurred between the ages of 12 and 13 years. Yamamoto et al suggested that the age of 11 years-old may be a pivotal point for humeral retrotorsion adaptation due to its close relationship to the timing of a growth spurt.[28] Hibberd et al[13] assessed both ROM and humeral retrotorsion and found that the largest change in IR loss and humeral retrotorsion coincided, occurring between the ages of 11-16 years. The timing of these studies suggests a link between alterations in humeral retrotorsion and shoulder IR ROM loss, but the timing is not clear. The results of a study conducted by Nakamizo et al[78] introduce more variability into these scenarios. In this study, Little League pitchers with GIRD (defined as $\geq 20°$ loss of IR ROM) did not demonstrate increased ER compared to their contralateral shoulder. Although humeral retrotorsion was not assessed, one would anticipate any alteration in bony torsion would be associated with increased ER along with decreased IR ROM, as was seen in the Hibberd study. The findings of Nakamizo et al[78] suggest that loss of IR ROM can precede the development of ER gain, at least in one sub-set of players with greater than normal alterations in IR ROM loss. The results of these studies as a group offer evidence for the need to further clarify the timing of humeral retrotorsion and shoulder ROM changes in young throwing athletes.

Does a *Window of Opportunity* Exist for Humeral Retrotorsion Adaptation?

Crockett et al[10] postulated that in order to achieve a high level of performance with less risk of shoulder injury, baseball players have a *window of opportunity* to adapt with increased humeral retrotorsion prior to growth arrest.[10] Yamamoto et al[28] found a trend that players who began pitching before the age of 11 demonstrated increased dominant arm humeral retrotorsion compared to those who began pitching after age 11. Although this trend was non-significant, the authors felt that this was mostly due to the small sample size, and asserted that players who begin playing baseball before the age of 11 are likely to have greater influence of their bony structure, offering improved opportunities to adapt to throwing. Literature regarding the influence of age of baseball participation on the degree of humeral retrotorsion expression is limited. Osbahr et al[26] did not quantify age of beginning baseball participation, but did find no significant correlation between the number of years pitched during the ages of 8-16 and the degree of humeral retrotorsion.

Further research should attempt to quantify how baseball participation, onset of baseball pitching, throwing volumes, and humeral retrotorsion are related. These findings could have implications regarding age recommendations for implementation of pitching during Little League participation, and in prevention of youth specific throwing injuries like Little League Shoulder. Furthermore, this information could help sports health professionals in identifying better ways to balance injury prevention tactics intended for the present and future of these athletes.

Is Humeral Retrotorsion Protective Against Injury?

Currently it is not clear what role humeral retrotorsion plays in the development of pathology in the throwing athlete, as studies have demonstrated both protective and contributory relationships. It appears that relative side-to-side differences in humeral retrotorsion may be more important in terms of injury potential than the overall degree or magnitude of retrotorsion positioning.[36,40] Similarly, the effect that humeral retrotorsion has on the degree of available shoulder ROM may play a very important role in terms of likelihood of injury, as loss of shoulder rotational motion has been identified as a risk factor for injury among these athletes.[9] Humeral retrotorsion has been demonstrated to closely correlate with increases in shoulder ER, but not as well with a loss of internal rotation. Although several studies have demonstrated that young throwers exhibit a pattern of increased ER and decreased IR,[3,31,35] further research focused on the young athlete is needed, in order to improve our understanding of the developmental process of humeral retrotorsion orientation, its effects on shoulder range of motion, and the interplay between bony and soft tissue changes within these athletes. This information could lead to more informed clinical decision-making and may help with injury prevention strategies by directing interventions toward the appropriate tissue.

It is important to point out that although it is not the focus of this review, the contribution of glenoid orientation is something that will need to be considered in future studies of the athlete shoulder. Investigators have determined that glenoid orientation changes are also found in throwing athletes and may play a protective role in throwing related injuries in adults.[10,25] however this has yet to be explored in the youth population.

CHAPTER 3: METHODOLOGY

INTRODUCTION

This chapter will serve as a complete outline of the methodology employed in the proposed research study, including a detailed description of measurement tools, data collection procedures, data analysis plan, and tentative timeline for completion. In addition, the chapter will discuss data from a completed pilot study to illustrate the reliability and validity of all measurements that will be used in this project.

RESEARCH METHODS TO BE EMPLOYED

Design and Intentions:

This research project utilized a cross-sectional matched group study design to explore the effects of throwing activity on the bony orientation of the proximal humerus and range of motion changes in shoulder rotation in young athletes. Specifically, we determined the effects of throwing activity and age on humeral torsion and glenohumeral ROM by comparing young throwing athletes to non-throwing athletes across ages 8-14. In addition, we identified the relationship between humeral torsion and glenohumeral range of motion.

Subjects:

A convenience sample of male athletes between the ages of 8-14 years-old was recruited from community little leagues, private baseball academies, youth soccer leagues, youth baseball leagues and private sports performance centers. The subjects were assigned to one of two groups based upon degree of overhead throwing they perform each year. The non-thrower group was operationally defined as those that participate in baseball less than 1 month per year and have not participated in any formal baseball activity for at least 12 months prior to data collection. For subjects to be assigned to the throwers group they must participate in baseball at least 6 months per year. Exclusion criteria included: ages outside those of interest, formal organized participation in other overhead sports such as tennis, squash or swimming; existing shoulder pathology that limits participation in sports, history of humeral fracture, and any known collagen disorders that result in joint hypermobility (i.e. Ehlers-Danlos syndrome).

Variables:

There were two independent variables in the study: throwing status and age. Throwing status was operationally defined as follows: Throwers will participate in baseball at least 6 months per year, whereas non-throwers will participate in overhead throwing sports less than 1 month per year. All subjects included were between the ages of 8-14 years old and were divided in three distinct groups based upon age: 8-10.5 year olds, 10.51-12.5 year olds and 12.51-14.99 year olds. These age ranges were chosen based upon the work of Yamamoto et al[28] and Hibberd et al.[13] Yamamoto determined that the age of 11 years was a critical age for throwing-dependent changes in humeral torsion. Hibberd found significant differences in side-to-side humeral torsion measurements between subjects aged 6-13 and those aged 14-18. They did not see a difference when analyzing the differences between the youngest subjects 6-10 and 11-13 years. Thus, chose to define our groups in the above age categories in order to allow for more detailed analysis of age dependent humeral torsion changes. The primary dependent variables were humeral retrotorsion and glenohumeral rotation ROM. Throwing velocity was also collected for future analysis regarding the relationship of humeral retrotorsion to performance. This analysis was not included within the current analysis. Additional information such as age, height, weight, dominant arm, throwing and sports participation history, and presence of any shoulder or elbow symptoms was also collected. The presence of symptoms was determined through direct yes/no questions as well as with the DASH Sports Module.[79] This is a 4-item self-report questionnaire that specifically addresses the function of the upper extremity in sports activities. The score is calculated with 0 representing the best possible score (no disability) and 100 being the worst score. For the throwers group, we also collected data regarding position played, number of teams playing for, and additional private instruction received outside of regular practice.

SPECIFIC PROCEDURES

Data collection occurred on-site at practice facilities, fields or performance centers. All protocols followed the regulations of the Institutional Review Board at NSU and other participating institutions. Parental consent and child assent was obtained prior to the collection of any data. Subjects were instructed to lie supine, on a standard treatment table for the measures of shoulder ROM and humeral retrotorsion. Bilateral shoulder ER at 90° abduction and IR at 90° abduction were assessed first using a digital inclinometer. A coin flip or uninvolved individual choice was used to randomly determine which side (left vs right) was assessed first. For external rotation, the shoulder was passively externally rotated until resistance was felt by the examiner and motion no longer occurred at the glenohumeral joint. A digital inclinometer was firmly placed along the ulnar aspect of the forearm to determine degree of rotation relative to vertical. (Figure 3.1) For IR, the subject's scapula was stabilized by a 2nd examiner by placing a posteriorly directed force to the anterior shoulder over the distal clavicle and coracoid process. (Figure 3.1) The end of motion was once again determined by the examiner where resistance was felt and when motion no longer occurred at the glenohumeral joint. The digital inclinometer was firmly pressed against the forearm and the angle of the forearm relative to vertical was recorded. These methods of assessing shoulder ROM have been described and studied previously by Wilk et al[80] and have shown good reliability. In addition to measurement of shoulder IR and ER, shoulder total range of motion (TROM) will be calculated by the following formula: IR at 90° + ER at 90° = TROM.

Figure 3.1. Measurement technique for shoulder external rotation and internal rotation

A B

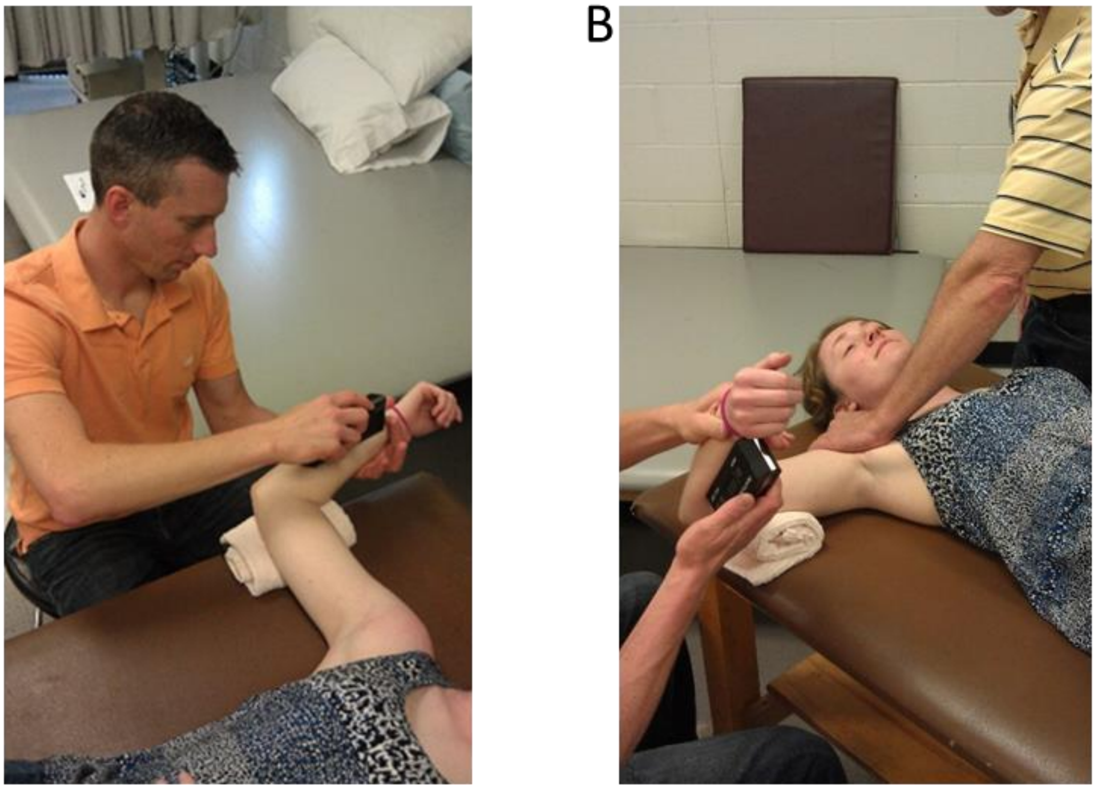


Figure 3.1. Illustration of stabilization method and digital inclinometer placement during measurement of shoulder external rotation (A) and internal rotation (B).

Humeral retrotorsion was assessed using diagnostic ultrasound (GE LOGIQe with 5-13MHz linear array transducer) utilizing the technique described by Myers et al.[49] This method has demonstrated excellent reliability and validity in the assessment of humeral retrotorsion.[49] The patient was positioned in supine with the shoulder to be measured in 90° of coronal plane abduction and neutral rotation, with the elbow flexed to 90°. (Figure 3.2) Two examiners were present to perform the measurement. Examiner 1 acted as the sonographer. This examiner placed the linear array ultrasound transducer onto the subject’s proximal humerus and identified the bicipital groove. The examiner utilized the following criteria ensure the same area of the bicipital groove was utilized for analysis: 1) the floor of the groove is horizontal and 2) the tubercles are of similar height and dimension. The examiner took care to ensure that the transducer was level to horizontal during the measurement procedure. To assist with this, a bubble level was firmly attached to the transducer and leveled to horizontal prior to assessment. This assisted the examiner in accurately orienting the transducer to horizontal during the measure. At this point, the subject’s arm was internally or externally rotated in order to align the apex of the ridges forming the bicipital groove, in such a way that they were horizontally oriented. (Figure 3.3) This position of orientation was maintained while examiner 2 took a measurement of forearm inclination. For this measurement, examiner 2 placed a digital inclinometer flush against the distal aspect of the subject’s ulna. (Figure 3.3) The inclinometer gave a digital measurement of the angle of the subject’s forearm relative to vertical and this number was recorded. Three measures of humeral torsion were taken and an average of those three were utilized for analysis. The identical testing procedure was then be carried out on the opposite shoulder.

Figure 3.2. Position of upper extremity for ultrasound assessment of humeral retrotorsion

Figure 3.2. Shoulder positioned in the coronal plane in neutral rotation for the assessment of humeral retrotorsion.

Figure 3.3. Assessment of humeral retrotorsion

Figure 3.3. Demonstrates of humeral retrotorsion assessment and ultrasound image of bicipital groove.

DATA ANALYSIS

All statistical analyses were conducted using Statistical Package for Social Sciences version 21.0 (SPSS Inc., Armonk, New York, USA). Descriptive data related to age, years of sports participation, and shoulder symptoms were calculated for each group. In addition, for the baseball group, additional information including age at which the player began playing baseball, yearly volume of baseball participation, position played, and independent pitching coaching was collected and displayed. Prior to analysis, the data was screened for missing information and normality (skewness and kurtosis) using visual inspection, graphing and statistical analysis. A two-way analysis of variance was performed with throwing status (yes/no) and age (8-10.5, 10.51-12.5, 12.51-14.99) as the primary factors. Dependent variables were side-to-side differences in humeral retrotorsion and shoulder ROM with $\alpha=0.05$ for all analyses. Interactions between age and throwing status were assessed, followed by determination of main effects for throwing status and age and post-hoc procedures as appropriate. In order to improve clarity and isolate the effects of throwing more specifically, an additional ANCOVA analysis was conducted utilizing age as a covariate. The correlation between ROM and degree of humeral retrotorsion were analyzed using Pearson Product Moment Correlation. Fisher r to z transformations were used to assess for group differences in correlation.

RESOURCE REQUIREMENT

The major resources required for completion of this project were as follows: diagnostic ultrasound machine, digital inclinometer, a portable treatment table, and statistical software. Arcadia University supported this project with use of the diagnostic ultrasound computerized system (LOGIQe from GE with advanced imaging pack and 12L linear array transducer 5-13MHz), as well as a digital inclinometer, dedicated office and laboratory space, and computers with statistical software for data collection and reduction.

The obvious other resource requirement was that of human subjects. We utilized effective recruiting strategies through capitalizing on the primary researchers' contacts in local sports organizations and sports performance academies. In addition, this study received grant funding from the though the Legacy Fund Grant which is supported by the Sports Physical Therapy Section of the American Physical Therapy Association. This funding was utilized in part to provide a subject honorarium which helped to facilitate effective recruitment of subjects.

RELIABILITY AND VALIDITY OF HUMERAL RETROTORSION MEASUREMENT

Literature reports show that ultrasound measurement of humeral retrotorsion has excellent intra and interrater reliability with intraclass correlation coefficients ranging from 0.94 to 0.98, and an average measurement error of 2.3°.[16,21]

The measurement of shoulder ROM was conducted utilizing standardized procedures that have been outlined by previous investigators.[13,16,69] Utilizing identical measurement procedures allowed for the most accurate comparison of our results to past publications. The reliability and precision of the outlined methods of shoulder rotation assessment has been established. Intrasession and intersession intraclass correlation coefficients were 0.985 and 0.988 with a standard error of measurement of 1.5° - 2.6°.[13]

PILOT STUDY

Assessment of Intra and Inter-examiner Reliability

In order to ensure that the proposed project can be completed successfully, and that measurements obtained following the project protocols are reliable and reproducible, we completed a pilot study which is described below.

Study Design

Intra and inter-examiner, within and between days reliability study

Objectives

To compare intra and inter-examiner reliability of ultrasound assessment of humeral torsion among novice examiners.

Rationale for the Study

Ultrasound (US) represents a potential method of determining bony versus soft tissue influence on shoulder rotation range of motion (ROM) which could help direct treatment. The reliability of utilizing US for the assessment of humeral torsion has been reported in the literature however, it is possible that due to the nature of the measurement technique, reliability may be highly operator-dependent. The purpose of this study was to determine the inter-rater and between session reliability humeral torsion measurements among novice examiners.

Methods

Institutional Review Board approval was obtained by Arcadia University. Humeral torsion was assessed bilaterally with ultrasound by two recently trained examiners in a group of 30 healthy individuals (mean age 26.48, range 19-62). The average of 3 measures was used for data analysis. Additionally, a single measure of shoulder external

(ER) and internal rotational (IR) range of motion in 90° abduction was collected using a digital inclinometer. Measurements were taken at two different time points, at least 48 hours apart in order to study both inter-rater and between-days reliability. Intraclass correlation coefficients (ICC 3,1) and 95% confidence intervals (CI) were calculated for each side.

Results

Mean (SD) for humeral torsion was 19.2° (10.3°) on the dominant and 25.4° (9.0°) on the non-dominant side (lower value represents greater retrotorsion). Mean (SD) for rotation ROM was 106.3° (12.8°) for ER and 41.1° (7.9°) for IR on the dominant side. Mean (SD) for rotation ROM was 99.8° (14.5°) for ER and 48.4° (7.5°) for IR on the non-dominant side. Inter-rater reliability values for the right (dominant) shoulder humeral torsion are reported in Table 3.1, while the values for the left (non-dominant) shoulder are reported in Table 3.2. Values for both intra-rater and between session measurements demonstrated excellent reliability similar to that reported by other investigators.

Table 3.1: Summary statistics for reliability of humeral retrotorsion assessment of dominant shoulder

	R RV (3K ICC)	**95% CI**	**SD**	**SEM**	**MDC**
Inter-rater Day 1	0.975	.95-0.99	10.41	1.65	4.56
Inter-rater Day 2	0.984	0.97-0.99	10.65	1.35	3.73
Intra-rater Day 1vs2 Rater 1	0.956	0.91-0.98	10.89	2.28	6.33
Intra-rater Day 1vs2 Rater 2	0.971	0.94-0.99	10.17	1.73	4.80

Table 3.2: Summary statistics for reliability of humeral retrotorsion assessment of non-dominant shoulder

	L RV (3K ICC)	95% CI	SD	SEM	MDC
Inter-rater Day 1	0.947	0.89-0.98	9.52	2.19	6.07
Inter-rater Day 2	0.957	0.91-0.98	9.39	1.95	5.39
Intra-rater Day 1vs2 Rater 1	0.925	0.84-0.96	9.16	2.51	6.95
Intra-rater Day 1vs2 Rater 2	0.913	0.82-0.96	9.75	2.88	7.97

Conclusions

Ultrasound has been proposed as a clinically useful method for determining bony versus soft tissue influence on shoulder rotational ROM, which may help direct treatment. These data suggest that humeral torsion measurements using US can be highly reliable among novice examiners. This may allow for more ease of clinical use as accurate measurements can be obtained without significant training.

CHAPTER 4: RESULTS

INTRODUCTION

The primary purpose of this study was to determine the effects of age and throwing activity on the development of humeral retrotorsion and shoulder range of motion (ROM). The secondary purpose was to analyze the influence of humeral retrotorsion on clinically measured shoulder ROM. This chapter will discuss the results related to this investigation. We will begin by presenting detailed descriptions of our study population which consisted of two groups of young athletes 8-14 years old. One group consisted of children who heavily participate in baseball, while the second group consists of a similarly aged and athletic individuals, who do not participate in baseball or other overhead throwing sports.

PARTICIPANTS

Data was collected for a total of 158 subjects. Five subjects ended up not meeting eligibility for inclusion after full review of sports participation history for the following reasons: did not play adequate amount of baseball to satisfy entrance criteria (n=3), and participated in competition level swimming (n=2). A total of 153 subjects were therefore included in data analysis. The subjects were divided into two groups based upon sports activity; throwers (n=85) and non-throwers (n=68). Subjects were then further classified into age categories for further analyses using the following age categories: 8-10.5 years, 10.51-12.5 years, and 12.51-14.99 years. Figure 4.1 illustrates the specifics of classification. Descriptive characteristics of each group are outlined in Tables 4.1 and 4.2. Comparison of means using independent samples t-test revealed no significant differences between thrower and non-thrower groups for age, height or weight.

Information regarding sports activity, participation volume, playing experience, and arm dominance are outlined in Tables 4.3-4.5.

Figure 4.1. Graphical outline of classification system utilized

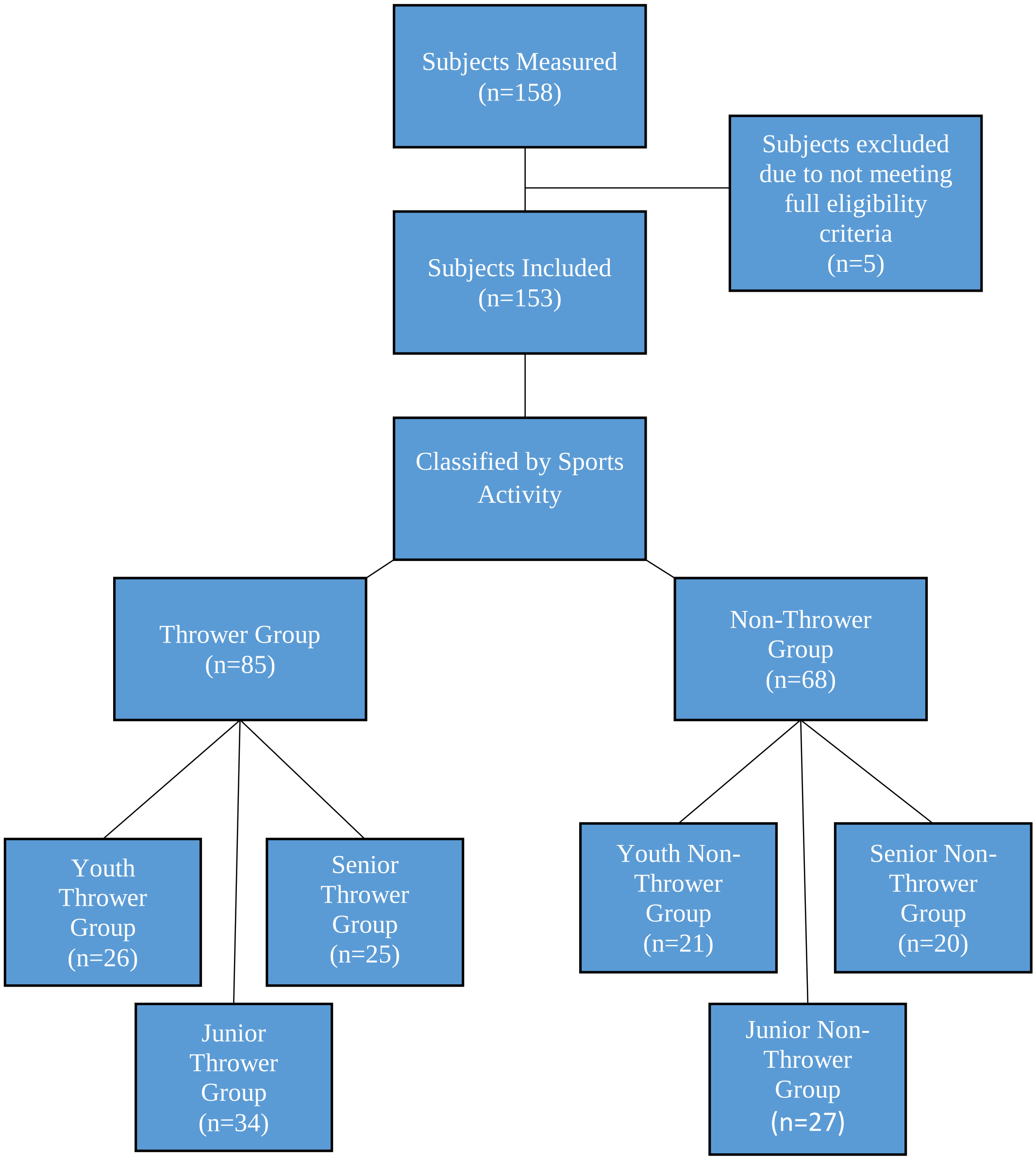


Table 4.1. Subject demographics

	Throwers				Non-Throwers				P
	Youth (n=26)	**Junior (n=34)**	**Senior (n=25)**	**All (n=85)**	**Youth (n=21)**	**Junior (n=27)**	**Senior (n=20)**	**All (n=68)**	
Age (yrs)	9.7 ± 0.6	11.6 ± 0.6	13.1 ± 0.4	11.5 ± 1.4	9.7 ± 0.6	11.2 ± 0.5	13.8 ± 0.7	11.5 ± 1.7	0.903
Hgt (In)	55.6 ± 3.6	58.5 ± 2.7	64.5 ± 4.1	59.3 ± 4.9	55.8 ± 3.7	57.5 ± 4.1	66.4 ± 6.3	59.8 ± 6.4	0.808
Wgt (lbs)	76.6 ± 17.9	88.7 ± 19.2	119.7 ± 30.9	94.1 ± 28.5	78.7 ± 15.4	86.8 ± 15.8	137.4 ± 40.5	99.2 ± 35.5	0.330

Values are mean ± SD (unless otherwise noted)
Independent samples t-test for overall group comparisons.

Table 4.2. Age (mean) for age groups, not separated by activity

	Mean Age (years)	**SD**
Youth Group (n=47)	9.7	0.63
Junior Group (n=61)	11.4	0.60
Senior Group (n=45)	13.4	0.69

Table 4.3. Baseball demographics of thrower group

	Youth (n=26)	**Junior (n=34)**	**Senior (n=25)**
Age began playing baseball (years)	4.5 ± 1.0	5.2 ± 1.1	5.5 ± 1.4
Playing experience (mean age – age began playing)	5.2 ± 1.1	6.4 ± 1.2	7.6 ± 1.5
Months played per year	9.1 ± 1.7	9.1 ± 2.3	9.0 ± 1.8
Number of pitchers (frequency)	21	25	22

Values are mean ± SD, unless otherwise indicated

Table 4.4. Non-Thrower sports participation

	Youth (n=21)	**Junior (n=27)**	**Senior (n=20)**
Basketball	7 (33.3%)	9 (33.3%)	17 (85.0%)
Soccer	13 (61.9%)	14 (51.9%)	1 (5%)
Lacrosse	-	2 (7.4%)	1 (5%)
Football	-	2 (7.4%)	-
Ice Hockey	-	-	1 (5%)
Track & Field	1 (4.8%)	-	-
Mean months per year participating in primary sport (mean ± SD)	9.4 ± 2.9	9.7 ± 2.7	8.8 ± 3.0

Values are frequencies unless otherwise indicated

Table 4.5. Arm Dominance

	Thrower Group	**Non-Thrower Group**
Right	75 (88.2%)	64 (94.1%)
Left	10 (11.8%)	4 (5.9%)

Values are frequencies

Specific Aim 1:

The first aim was to determine the effects of throwing activity and age on humeral retrotorsion and glenohumeral ROM by comparing young throwing athletes to non-throwing athletes of equivalent sports participation activity across ages 8-14 years-old. Side-to-side differences were calculated for all variables by subtracting the non-dominant value from the dominant arm value (dominant – non-dominant).

Analysis Specific Aim 1:

To review, subjects participating in the study were grouped according to throwing status and age level. Data screening revealed no missing data for any of the variables of interest. Skewness and kurtosis values were all between -1 and 1, indicating normal distribution. A two-way analysis of variance was performed using throwing status (yes/no) and age (Youth 8-10.5 years, Junior 10.51-12.5 years, Senior 12.51-14.99) as the primary factors. Separate ANOVA analyses were conducted for each dependent variable: Side-to-side difference in humeral retrotorsion, side-to-side difference in shoulder total range of motion (TROM), Glenohumeral Internal Rotation Difference (GIRD) and Glenohumeral External Rotation Difference (GERD).

Results Specific Aim 1:

A two-way analysis of variance was conducted to investigate side-to-side differences in humeral retrotorsion due to throwing activity and age. ANOVA results are presented in Table 4.6. The results demonstrate no significant interaction between factors [$F(2, 147) = 0.021$, $p = 0.979$, partial $\eta^2 < 0.001$], which is graphically represented in Figure 4.2. Analysis of main effects demonstrated there was a significant main effect for both throwing status [$F(1, 147) = 6.62$, $p = 0.011$, partial $\eta^2 = 0.043$] and age category [$F(2, 147) = 3.84$, $p = 0.024$, partial $\eta^2 = 0.050$], indicating that side-to-side differences in humeral retrotorsion tend to increase as one ages and if one participates in throwing sports. Analysis of means between activity groups, across all ages, demonstrates a difference of 3.9°, with those athletes participating in throwing sports having a larger side-to-side difference between the dominant and non-dominant arms. Post-hoc testing with Bonferroni correction was conducted to determine which age categories were significantly different. Results revealed significant differences existed between the youth group and senior group (p = 0.036) with a mean difference of -4.9°. There were no significant differences between the youth and junior groups (p = 0.071) or the junior and senior groups (p = 1.00). The mean values for all variables and side-to-side asymmetries are presented in Tables 4.7-4.10 and graphically outlined in Figures 4.3-4.4. A summary table of activity and age group differences is presented in Table 4.11.

Figure 4.2- Line graph of side-to-side differences in humeral retrotorsion

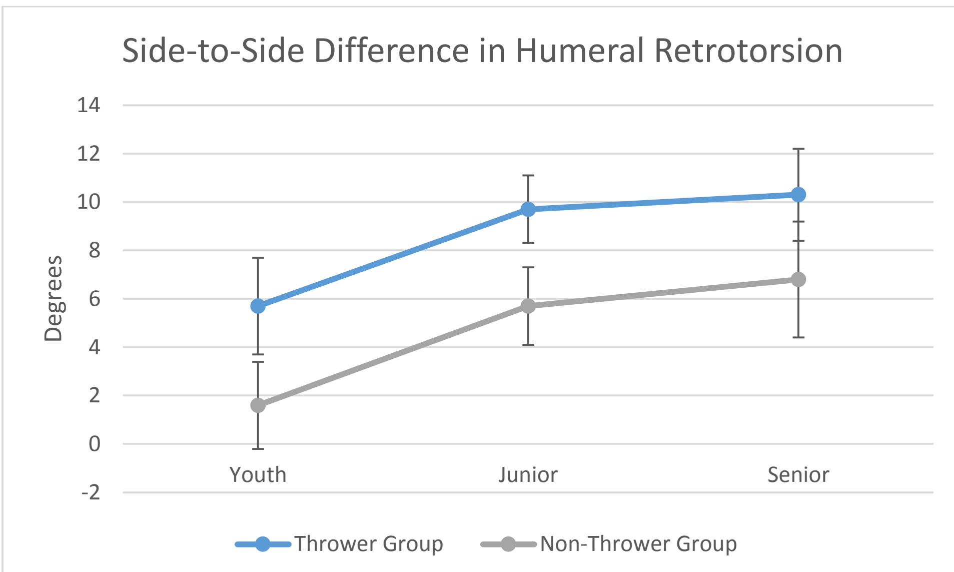


Table 4.6. Two-way ANOVA summary table for side-to-side difference in humeral retrotorsion

Source	SS	df	MS	F	p	ES
Between Treatments	1234.68	5	246.94			
Age Group	650.59	2	325.29	3.84	0.024	0.050
Throwing Activity	560.09	1	560.09	6.62	0.011	0.043
Age group x Throwing	3.54	2	1.77	0.021	0.979	<0.001
Within Treatments	12441.06	147	84.63			
Total	21032.51	153				

Table 4.7 – Humeral Retrotorsion (HRT), Internal Rotation Range of Motion (IRROM), External Rotation Range of Motion (ERROM) and Total Range of Motion (TROM) by *age group*

	Youth Group (n=47)		**Junior Group (n=61)**		**Senior Group (n=45)**	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
HRT	78.6 ± 1.8	74.7 ± 1.8	72.8 ± 1.4	64.9 ± 1.4	70.4 ± 2.1	61.6 ± 1.9
IRROM	41.2 ± 1.3	44.8 ± 1.1	42.9 ± .8	46.2 ± 1.0	38.5 ± 1.4	45.7 ± 1.2
ERROM	125.1 ± 1.3	122.8 ± 1.5	124.8 ± 1.2	120.6 ± 1.3	124.1 ± 1.7	119.7 ± 1.4
TROM	166.3 ± 1.8	167.6 ± 1.8	167.8 ± 1.4	166.8 ± 1.4	162.6 ± 1.6	165.5 ± 1.7

Values expressed as mean ± SE. HRT, Humeral Retrotorsion; IRROM, Internal Rotation Range of Motion; ERROM, External Rotation Range of Motion; TROM, Total Range of Motion

Table 4.8 – Side-to-Side asymmetry in Humeral Retrotorsion (HRT), Glenohumeral Internal Rotation Difference (GIRD), Glenohumeral External Rotation Difference (GERD), difference in Total Range of Motion (TROM) for *age group*

	Youth Group (n=47)	**Junior Group (n=61)**	**Senior Group (n=45)**
Difference HRT	3.9 ± 1.4	8.0 ± 1.1	8.8 ± 1.5
GIRD	-3.6 ± 1.2	-3.3 ± 0.8	-7.2 ± 1.0
GERD	2.2 ± 1.3	4.3 ± 1.0	4.4 ± 1.3
Difference in TROM	-1.4 ± 1.4	0.9 ± 0.9	-2.9 ± 1.1

Values expressed as mean ± SE. HRT, Humeral Retrotorsion; GIRD, Glenohumeral Internal Rotation Difference; GERD, Glenohumeral External Rotation Difference; TROM, Total Range of Motion.

Figure 4.3 – Graphic representation of side-to-side asymmetry by *age group*

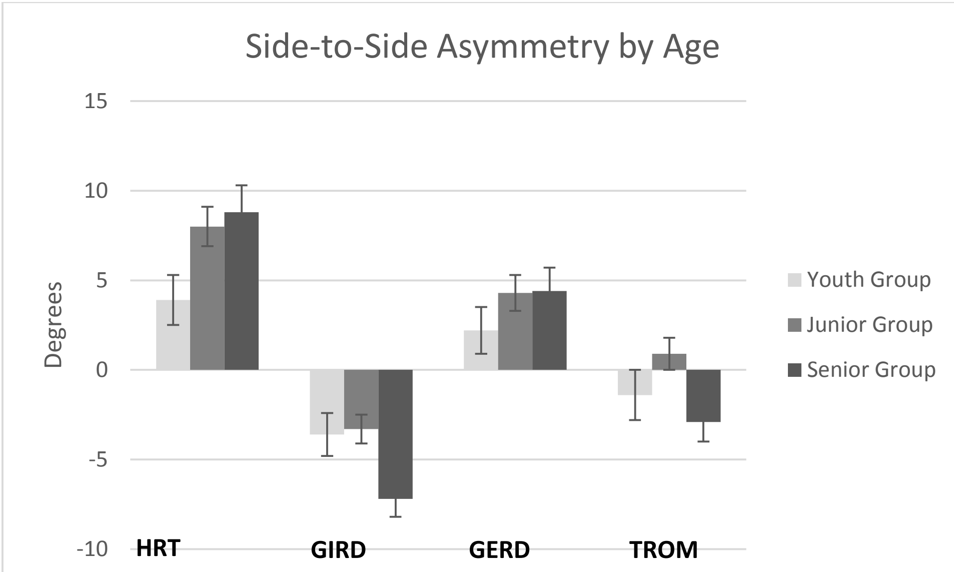


Table 4.9 - Humeral Retrotorsion (HRT), Internal Rotation Range of Motion (IRROM), External Rotation Range of Motion (ERROM) and Total Range of Motion (TROM) by *throwing status.*

	Thrower Group (n=85)		**Non-Thrower Group (n=68)**	
	Dominant	Non-Dominant	Dominant	Non-Dominant
HRT	75.1 ± 1.2	66.4 ± 1.4	72.3 ± 1.8	67.5 ± 1.6
IRROM	39.8 ± 0.8	45.8 ± 0.8	42.6 ± 1.1	45.3 ± 0.9
ERROM	124.9 ± 1.0	119.8 ± 0.9	124.3 ± 1.2	122.5 ± 1.4
TROM	164.8 ± 1.3	165.7 ± 1.2	166.9 ± 1.3	167.8 ± 1.5

Values expressed as mean ± SE. HRT, Humeral Retrotorsion; IRROM, Internal Rotation Range of Motion; ERROM, External Rotation Range of Motion; TROM, Total Range of Motion

Table 4.10 - Side-to-Side difference in Humeral Retrotorsion (HRT), Glenohumeral Internal Rotation Difference (GIRD), Glenohumeral External Rotation Difference (GERD), difference in Total Range of Motion (TROM) for *throwing status.*

	Thrower Group (n=85)	Non-Thrower Group (n=68)
Difference HRT	8.6 ± 1.0	4.7 ± 1.1
GIRD	-6.0 ± 0.8	-2.7 ± 0.9
GERD	5.1 ± 0.9	1.8 ± 1.1
Difference in TROM	-0.8 ± 0.9	-0.9 ± 0.9

Values expressed as mean ± SE. HRT, Humeral Retrotorsion; GIRD, Glenohumeral Internal Rotation Difference; GERD, Glenohumeral External Rotation Difference; TROM, Total Range of Motion.

Figure 4.4 – Graphic representation of side-to-side asymmetry by *throwing status*

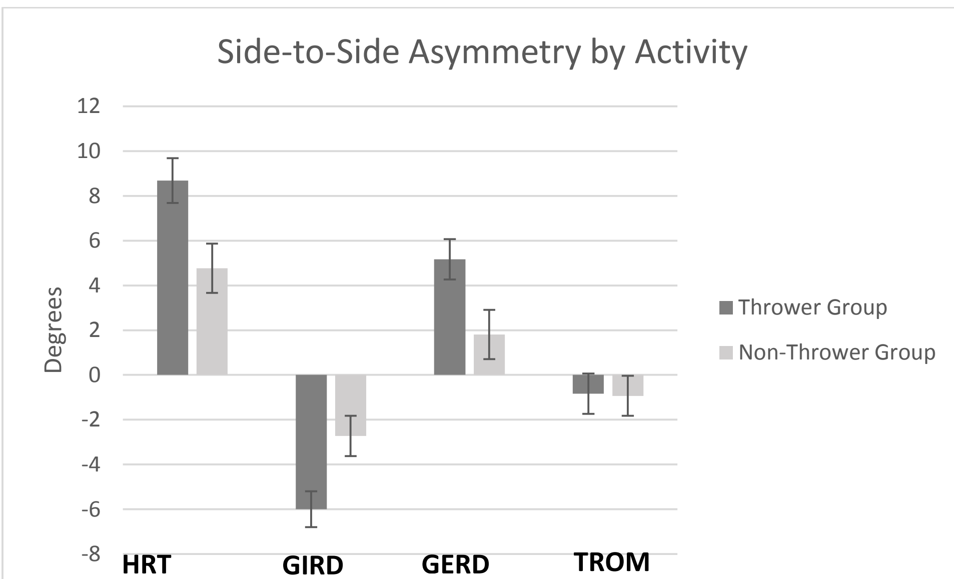


Table 4.11. Summary table of group comparisons for side-to-side differences in humeral retrotorsion

	Thrower and Non-Thrower	Youth Group and Junior Group	Youth Group and Senior Group	Junior Group and Senior Group
Mean Difference	3.9° (0.9,6.9)	4.1 (-0.2,8.4)	4.9° (0.2,9.5)	0.8 (-3.5,5.2)
p-value	0.011	0.071	0.036	1.00

Values expressed as mean and 95% CI

A screen for outliers was conducted using boxplots (Figure 4.5), which identified 5 data points as outliers (n=4 in throwing group; n=1 in non-throwing group) for the dependent variable of side-to-side difference in humeral retrotorsion. Removing these outliers from the analysis created a small change in the ANOVA results (Tables 4.12-4.13). The interaction between factors remained not significant [$F(2, 142) = 0.050$, $p = 0.951$, partial $\eta^2 = 0.001$] (Figure 4.6), and the analysis of main effects indicates that throwing status remains significant [$F(1, 142) = 8.591$, $p = 0.004$, partial $\eta^2 = 0.057$], but the effect of age becomes marginally significant [$F(2, 142) = 3.050$, $p = 0.050$, partial $\eta^2 = 0.041$]. Indeed, post-hoc testing utilizing Bonferroni method fails to show any significant differences between any age groups ($p > .05$). In summary, after removing the outliers from the analysis, there continued to be statistically significant changes in side-to-side difference in humeral retrotorsion related to activity groups (thrower versus non-thrower), but changes related to age groups were no longer statistically significant.

Figure 4.5 – Box Plot demonstrating outliers for side-to-side difference in humeral retrotorsion

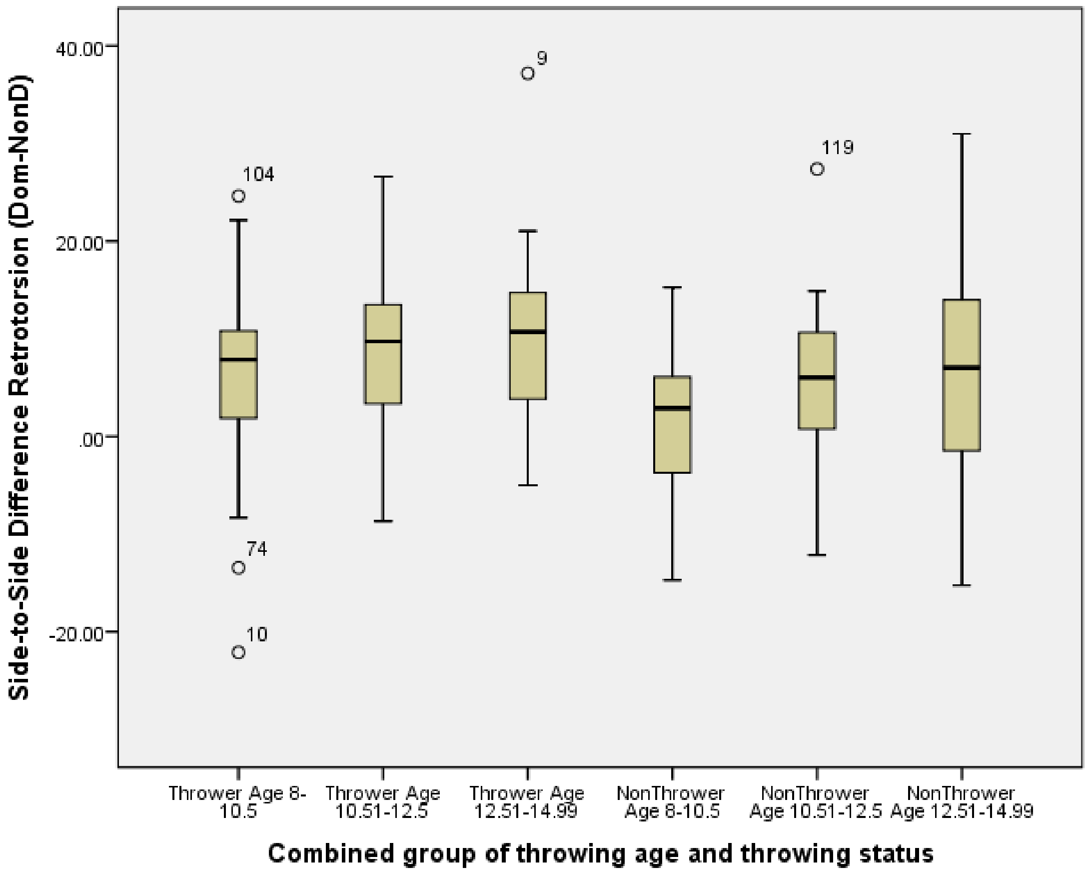


Figure 4.6 – Line graph of side-to-side differences in humeral retrotorsion with outliers removed

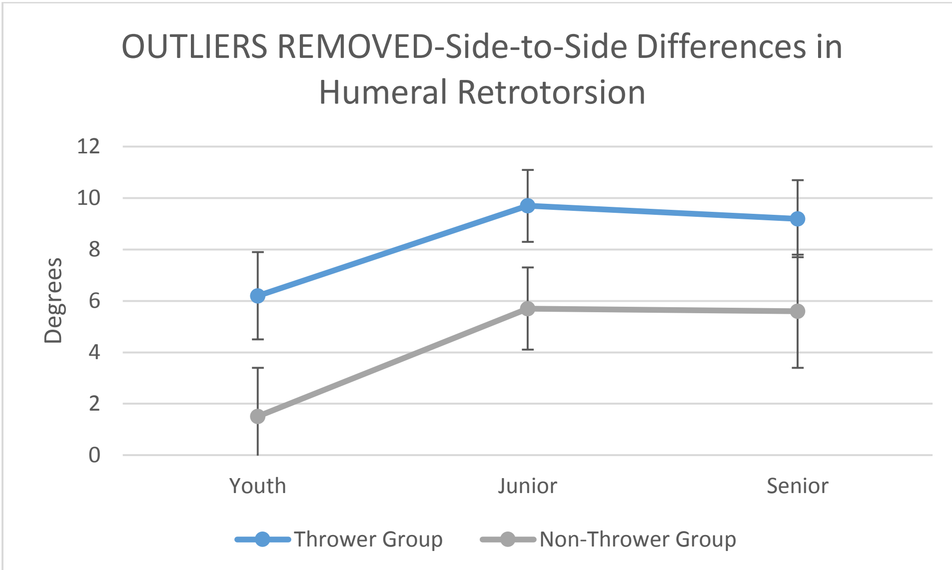


Table 4.12. Two-Way ANOVA Summary Table for side-to-side difference in humeral retrotorsion with *<u>outliers removed</u>*

Source	SS	df	MS	F	p	ES
Between Treatments	1064.539	5	212.908			
Age Group	430.361	2	215.180	3.050	0.050	0.041
Throwing Activity	606.149	1	606.149	8.591	0.004	0.057
Age group x Throwing	7.105	2	3.553	0.050	0.951	0.001
Within Treatments	10019.046	142	70.557			
Total	17696.565	148				

Table 4.13. Group comparisons for side-to-side differences in humeral retrotorsion with *__outliers removed__*

	Thrower and Non-Thrower	**Youth Group and Junior Group**	**Youth Group and Senior Group**	**Junior Group and Senior Group**
Mean Difference	4.1° (1.3 , 6.9)	3.9° (-0.1 , 7.9)	3.5° (-0.8 , 7.9)	0.3° (-3.7 , 4.4)
p-value	0.003	0.061	0.157	1.00

Values expressed as mean and 95% CI

In order to improve our clarity in analysis and truly determine the effect of throwing on humeral retrotorsion, a separate ANCOVA was conducted with the outliers excluded (n=148) and using age as a covariate. This analysis allowed for statistical control of age and more precision, as age will now be factored as a continuous variable (rather than the categorical classification utilized in ANOVA analysis). The independent (Thrower versus Non-Thrower) and dependent variables (side-to-side difference in humeral retrotorsion) remained consistent with ANOVA analysis. After adjusting for the effect of age, there were significant differences noted between groups [$F(1,145) = 9.074$, $p = 0.003$, partial $\eta^2 = 0.059$]. Table 4.14 presents unadjusted and adjusted group means for the analysis.

In summary, our results indicate that the activity of throwing results in a difference in side-to-side asymmetry in humeral retrotorsion. Overall, side-to-side differences in humeral retrotorsion are greater for throwing athletes (8.6°) than for non-throwing athletes (4.7°).

There does seem to be a trend for side-to-side differences in humeral retrotorsion to grow larger with age, however, this effect of age is not consistent in our data. When analyzing the effects of age on humeral retrotorsion (irrespective of activity grouping) there was a significant difference between the youth group (mean age 9.7 years) and the senior group (mean age 14.8 years), but no differences between the junior group (mean age 11.5 years) and any of the other groups. (Tables 4.7-4.8, Figure 4.3) However, after removing outliers from our analysis, the effect of age was diminished becoming only marginally significant in the ANOVA analysis ($p = 0.050$) with less-sensitive pairwise comparison post-hoc testing unable to find any significant differences between age groups.(Tables 4.12-4.13) In order to remove the effects of age from our analysis and isolate the effect of throwing activity on side-to-side differences in humeral retrotorsion, an ANCOVA procedure was conducted utilizing age as a covariate. These results indicate that the effects of throwing activity remain significant ($p=0.003$), with throwing athletes having greater side-to-side differences (8.5° versus 4.3°) and greater degree of retrotorsion present on the dominant side. (Table 4.14)

Table 4.14 –Table of adjusted and unadjusted group means for side-to-side difference in humeral retrotorsion with *<u>outliers removed</u>*

	Adjusted Mean	Unadjusted Mean
Thrower Group	8.5	8.5
Non-Thrower Group	4.3	4.3

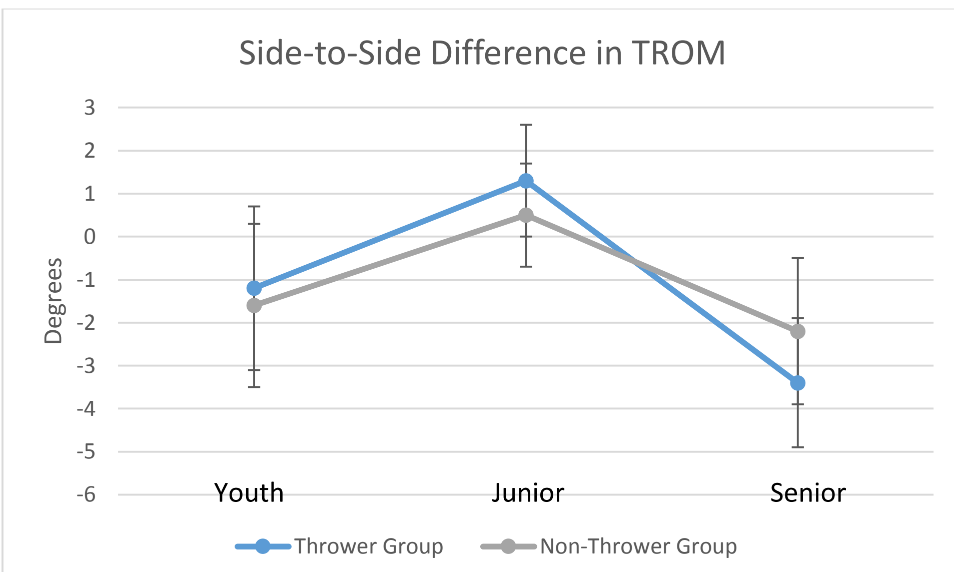
Additional two-way ANOVA analyses were performed separately to determine the effects of age and throwing activity on side-to-side asymmetry in shoulder TROM, GIRD and GERD. These ANOVA results are represented in Tables 4.15-4.19 and Figures 4.3-4.4. Results demonstrate no significant interaction [$F(2,147) = 0.223$, $p = 0.800$, partial $\eta^2 = 0.003$] (Figure 4.7) or main effects for changes in side-to-side differences in shoulder TROM with throwing activity [$F(1, 147) < 0.001$, $p = 0.994$, partial $\eta^2 < 0.001$] or age [$F(2, 147) = 2.88$, $p = 0.059$, partial $\eta^2 = 0.038$]. The relationship of these variables with GIRD is different. ANOVA results (Tables 4.16-4.17 and Figure 4.8) indicate no significant interaction [$F(2, 147) = 0.391$, $p = 0.677$, partial $\eta^2 = 0.005$] for age and throwing status. The main effects for both throwing status [$F(1, 147) = 8.62$, $p = 0.004$, partial $\eta^2 = 0.055$] and age group [$F(2, 147) = 4.37$, $p = 0.014$, partial $\eta^2 = 0.056$] were significant. Throwing athletes had 3.3° more GIRD (less IR ROM on dominant side) than non-throwing athletes with a side to side difference of 6.0° for throwers versus 2.7° for non-throwers. When comparing age groups, there was a loss of dominant arm IR motion within the oldest age groups who demonstrated a 7.2° loss of IR on the dominant side. Finally, for GERD the results showed no significant interaction, (Figure 4.9) but there was a significant main effect present for throwing activity [$F(1, 147) = 5.972$, $p = 0.016$, partial $\eta^2 = 0.039$], with throwers demonstrating a 5.2° gain in ER on the dominant side. (Tables 4.18-4.19)

In summary, these results indicate that there is no significant overall effect of age or throwing activity on a difference in shoulder TROM. However, a loss of shoulder internal rotation on the dominant side is significantly altered by both age and throwing activity. The degree of ER present is affected by throwing status, with a net gain in ER motion on the dominant side.

Table 4.15. Two-way ANOVA summary table for side-to-side difference in TROM

Source	SS	df	MS	F	p	ES
Between Treatments	424.02	5	84.81			
Age Group	369.01	2	184.50	2.88	0.059	0.038
Throwing Activity	0.004	1	0.004	<0.001	0.994	<0.001
Age group x Throwing	28.54	2	14.29	0.223	0.800	0.003
Within Treatments	9426.89	147	64.13			
Total	9969.15	153				

Figure 4.7. Line graph of side-to-side difference in TROM for all age groups



Line graph demonstrates some interaction between factors, however not significant

Table 4.16. Two-Way ANOVA summary table for GIRD

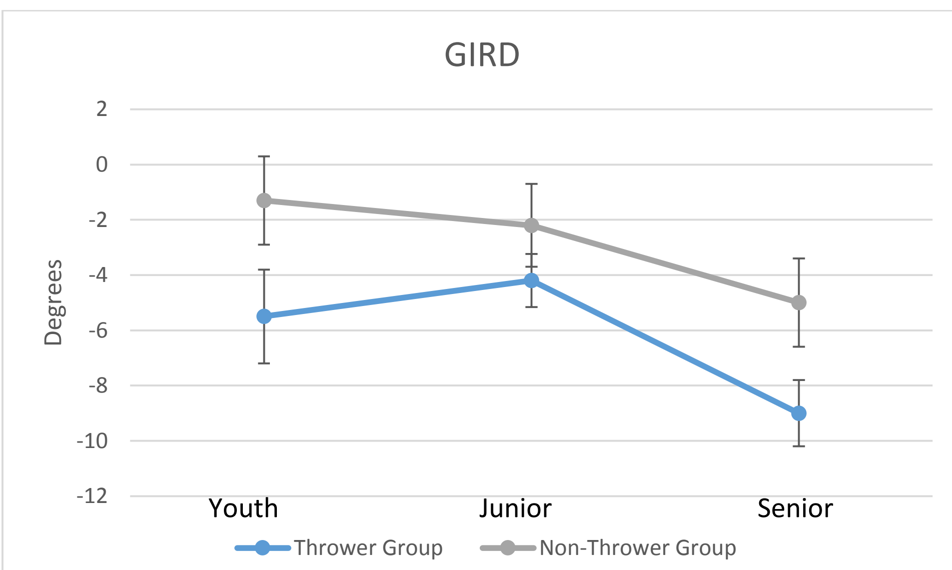
Source	SS	df	MS	F	p	ES
Between Treatments	895.99	5	149.20			
Age Group	434.28	2	217.14	4.37	0.014	0.056
Throwing Activity	428.24	1	428.24	8.62	0.004	0.055
Age group x Throwing	38.85	2	19.43	.391	0.677	0.005
Within Treatments	7301.35	147	49.67			
Total	11360.28	153				

Table 4.17. Summary table for group comparisons for GIRD

	Thrower Group and Non-Thrower Group	Youth Group and Junior Group	Youth Group and Senior Group	Junior Group and Senior Group
Mean Difference	-3.3 (-5.6 , -0.9)	-0.3 (-3.6 , 2.9)	3.6 (0.02 , 7.1)	3.9 (0.5 , 7.2)
p-value	0.006	1.00	0.048	0.016

Values expressed as mean and 95% CI

Figure 4.8. Line graph demonstrating side-to-side difference in internal rotation (GIRD) for all age groups



Line graph demonstrates no significant interaction between factors

Table 4.18. Two-Way ANOVA summary table for side-to-side difference in GERD

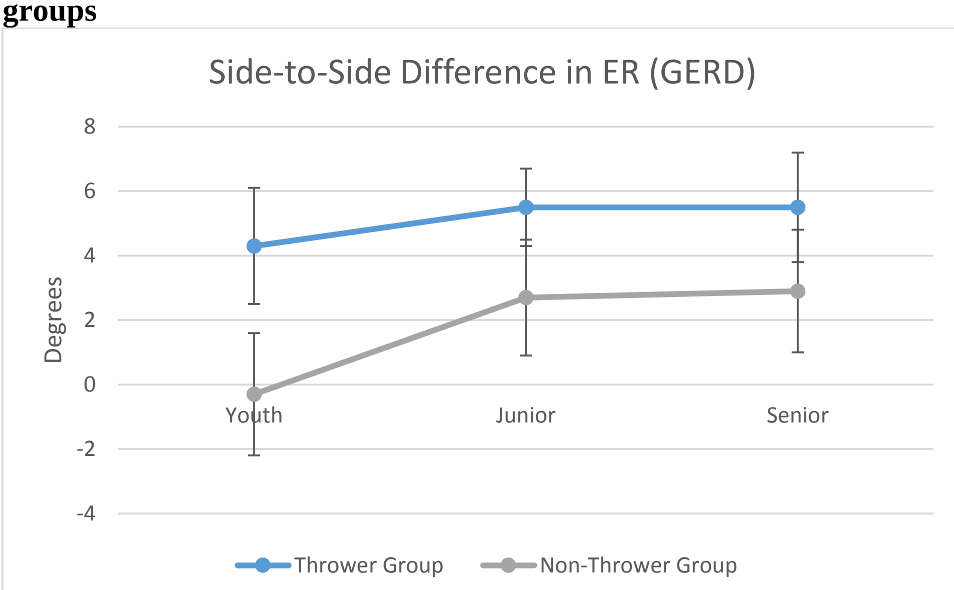
Source	SS	df	MS	F	p	ES
Between Treatments	588.71	5	117.742			
Age Group	148.44	2	74.22	1.041	0.356	0.014
Throwing Activity	425.619	1	425.619	5.972	0.016	0.039
Age group x Throwing	27.621	2	13.810	0.194	0.824	0.003
Within Treatments	10476.092	147	71.266			
Total	13122.902	153				

Table 4.19. Group comparisons for GERD

	Thrower Group and Non-Thrower Group	Youth Group and Junior Group	Youth Group and Senior Group	Junior Group and Senior Group
Mean Difference	3.4 (0.6 , 6.0)	2.0 (-1.9 , 5.9)	2.1 (-2.1, 6.3)	0.1 (3.9 , 4.1)
p-value	0.016	0.660	0.698	1.00

Values expressed as mean and 95% CI

Figure 4.9. Line graph illustrating side-to-side difference in ER (GERD) for all age groups



Line graph for side-to-side difference in ER demonstrates no interaction among factors.

Our prior analysis firmly established that there is a clear influence of throwing activity on humeral retrotorsion, creating larger side-to-side asymmetry with higher degrees of retrotorsion on the dominant side. A secondary analysis was then conducted in order to gain a more detailed understanding of the influence of age group on the changes in humeral torsion, and the relationship of these changes to shoulder range of motion within the thrower and non-thrower groups independently. Paired samples t-tests were utilized to assess differences between limbs in each age group for humeral retrotorsion, glenohumeral ER, glenohumeral IR and TROM for both throwers and non-throwers. (Table 4.20 and 4.21) In addition, separate one-way ANOVA analyses were performed for the thrower group and non-thrower groups, with each having the same 3 age categories described previously (youth, junior, senior). Separate analyses were performed for each of the following dependent variables: Side-to-Side asymmetry in humeral retrotorsion, asymmetry in ER (Glenohumeral External Rotation Difference (GERD)), asymmetry in IR (Glenohumeral Internal Rotation Deficit (GIRD)), and asymmetry in total range of motion (TROM).

Table 4.20 – Humeral Retrotorsion (HRT), Internal Rotation Range of Motion (IRROM), External Rotation Range of Motion (ERROM) and Total Range of Motion (TROM) within age categories of *Throwing Group*

	Youth Group (n=26)		**Junior Group (n=34)**		**Senior Group (n=25)**	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
HRT	80.0 ± 2.1	74.2 ± 2.6	74.8 ± 1.9	65.1 ± 1.9	70.4 ± 2.1	60.1 ± 2.2
IRROM	38.9 ± 1.9	44.4 ± 1.8	42.6 ± .9	46.8 ± 1.2	37.0 ± 1.6	46.0 ± 1.4
ERROM	125.3 ± 1.8	121.0 ± 1.8	125.6 ± 1.6	120.1 ± 1.4	123.6 ± 2.0	118.1 ± 1.8
TROM	164.3 ± 2.5	165.5 ± 2.1	168.3 ± 1.9	167.0 ± 1.9	160.7 ± 2.3	164.1 ± 2.3

Values are mean ± SE

Table 4.21 – Humeral Retrotorsion (HRT), Internal Rotation Range of Motion (IRROM), External Rotation Range of Motion (ERROM) and Total Range of Motion (TROM) within age categories of *Non-Throwing Group*

	Youth Group (n=21)		Junior Group (n=27)		Senior Group (n=20)	
	Dominant	**Non-Dominant**	**Dominant**	**Non-Dominant**	**Dominant**	**Non-Dominant**
HRT	76.8 ± 3.2	75.3 ± 2.6	70.2 ± 1.9	64.5 ± 2.1	70.2 ± 4.1	63.4 ± 3.4
IRROM	43.9 ± 1.6	45.2 ± 1.1	43.2 ± 1.5	45.4 ± 1.6	40.3 ± 2.4	45.4 ± 2.1
ERROM	124.6 ± 1.7	124.9 ± 2.5	123.7 ± 1.8	121.0 ± 2.5	124.6 ± 2.9	121.8 ± 2.3
TROM	168.6 ± 2.6	170.2 ± 2.9	167.0 ± 2.1	166.5 ± 2.2	165.0 ± 2.1	167.2 ± 2.6

Values are mean ± SE

In throwing athletes, paired samples t-tests revealed significant differences between the dominant and non-dominant limbs for humeral retrotorsion, glenohumeral ER, glenohumeral IR for all age groups and difference in TROM for the senior group only. In the non-throwing group, there were no significant differences between dominant and non-dominant sides for humeral retrotorsion, glenohumeral ER or TROM for any age group. There was a significant difference for glenohumeral IR, but only within the senior group. (Figures 4.10-4.17)

ANOVA results for side-to-side asymmetries in the throwing athletes (Table 4.22) indicated no significant differences existed for any of the assessed variables with the exception of GIRD ($F_{2,82}$ = 3.688; p = .029) between the junior – senior age groups (mean difference 4.8° (95% CI 0.4 , 9.1); p = .027). (Figure 4.14) Non-Throwers demonstrated no significant differences between age groups for any of the assessed variables. (Table 4.23)

Table 4.22 - Side-to-Side difference in Humeral Retrotorsion (HRT), Glenohumeral Internal Rotation Difference (GIRD), Glenohumeral External Rotation Difference (GERD), difference in Total Range of Motion (TROM) for within age categories of *Throwing Group*

	Youth Group (n=26)	Junior Group (n=34)	Senior Group (n=25)
Difference HRT	5.7 ± 2.0	9.7 ± 1.4	10.2 ± 1.9
GIRD	-5.5 ± 1.7	-4.1 ± .96	-8.9 ± 1.2
GERD	4.3 ± 1.7	5.5 ± 1.2	5.5 ± 1.7
Difference TROM	-1.2 ± 1.9	1.3 ± 1.3	-3.4 ± 1.5

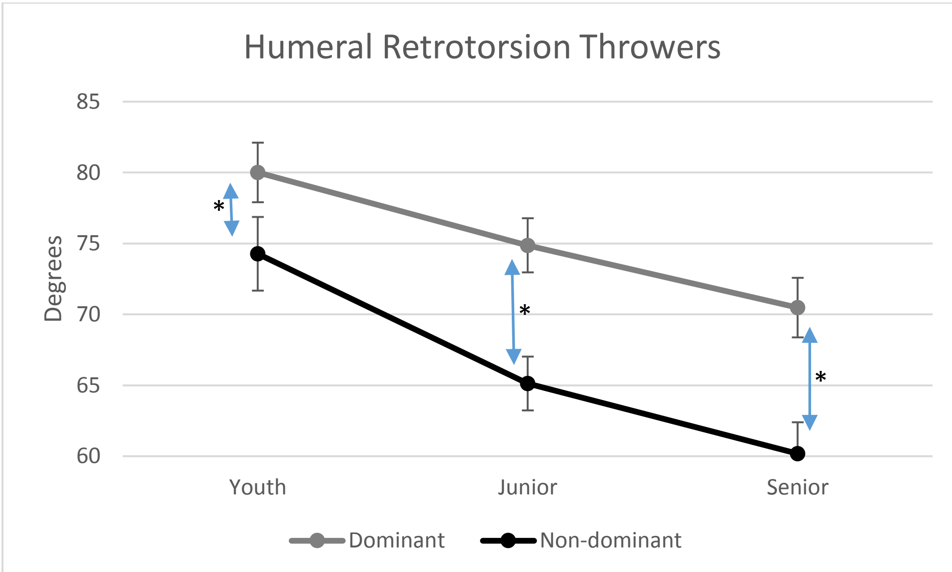
Values are mean ± SE

Table 4.23 - Side-to-Side difference in Humeral Retrotorsion (HRT), Glenohumeral Internal Rotation Difference (GIRD), Glenohumeral External Rotation Difference (GERD), difference in Total Range of Motion (TROM) for within age categories of *Non-Throwing Group*

	Youth Group (n=21)	Junior Group (n=27)	Senior Group (n=20)
Difference HRT	1.5 ± 1.8	5.6 ± 1.6	6.8 ± 2.4
GIRD	-1.2 ± 1.6	-2.1 ± 1.5	-5.0 ± 1.6
GERD	-0.3 ± 1.9	2.6 ± 1.8	2.8 ± 1.9
Difference TROM	-1.6 ± 1.9	0.5 ± 1.2	-2.1 ± 1.7

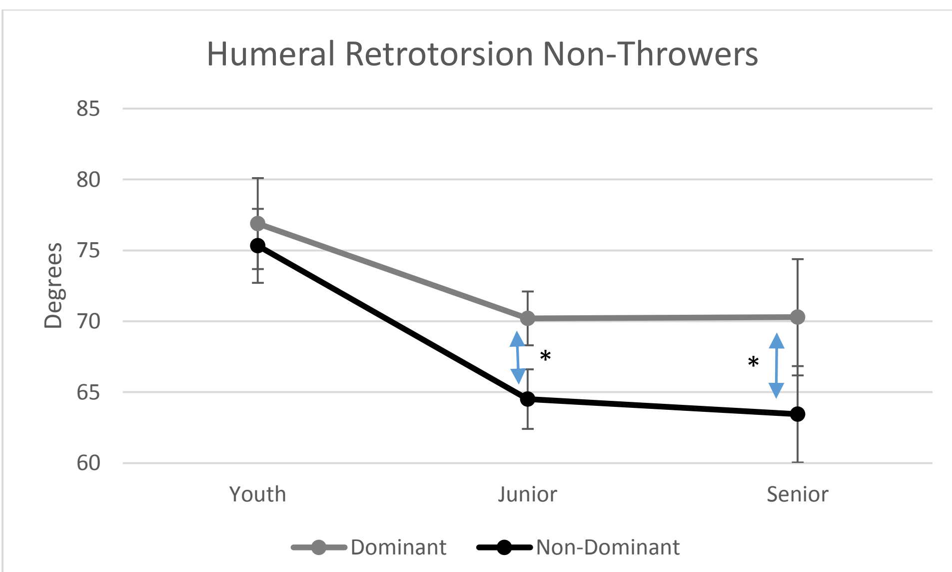
Values are mean ± SE

Figure 4.10- Dominant to non-dominant comparison for humeral retrotorsion in throwing group



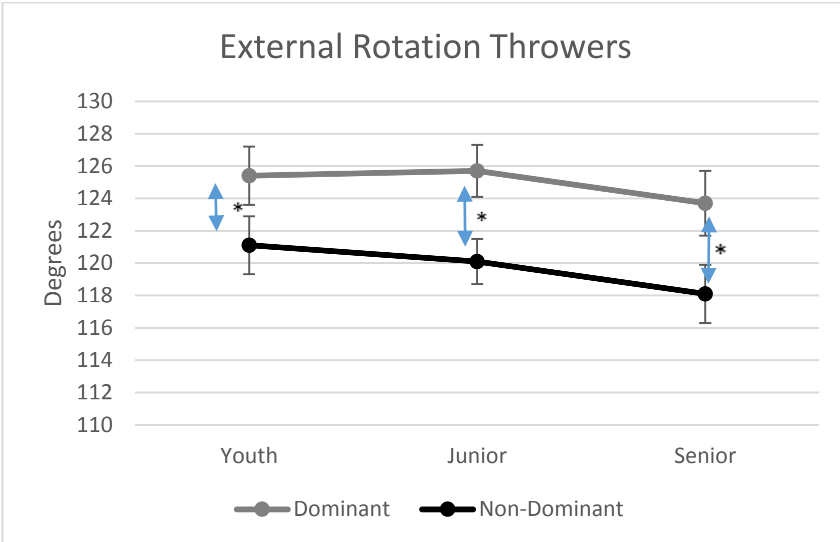
***Significant difference (p < .05)**

Figure 4.11 – Dominant to non-dominant comparison for humeral retrotorsion in non-throwing group



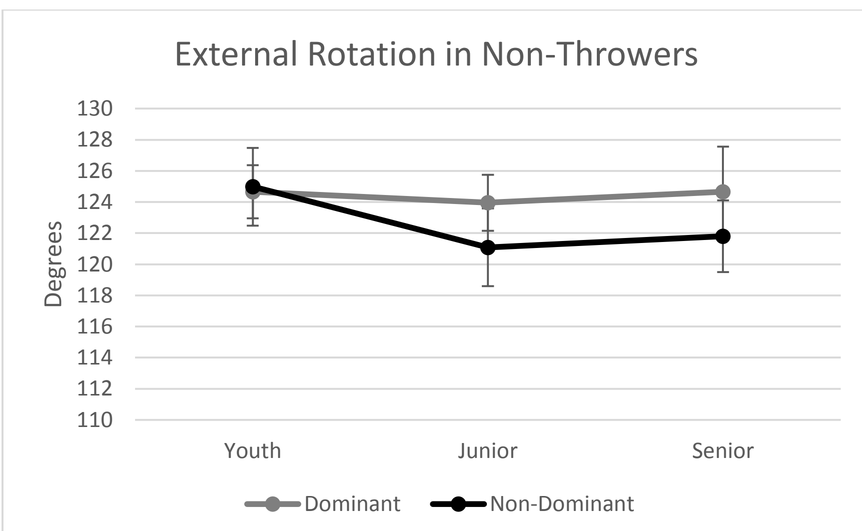
*significant difference (p < .05)

Figure 4.12- Dominant to non-dominant comparison for external rotation in throwing group



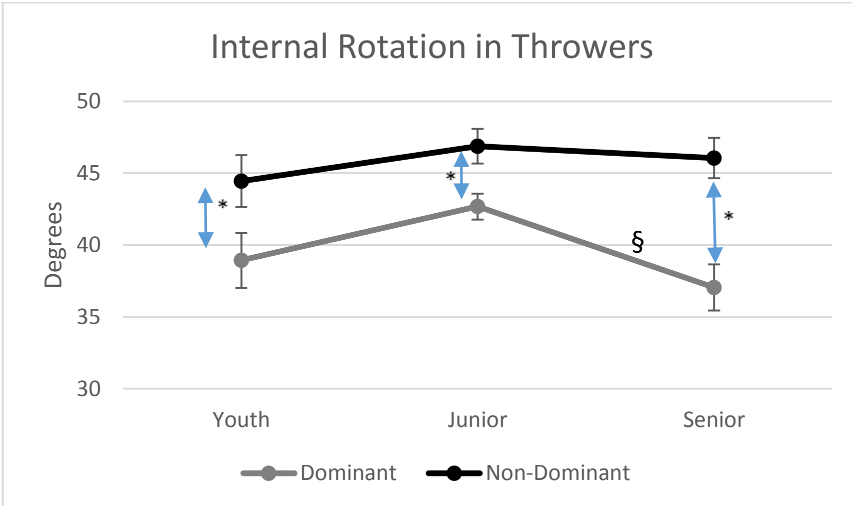
*Significant difference ($p < .05$)

Figure 4.13- Dominant to non-dominant comparison for external rotation in non-throwing group



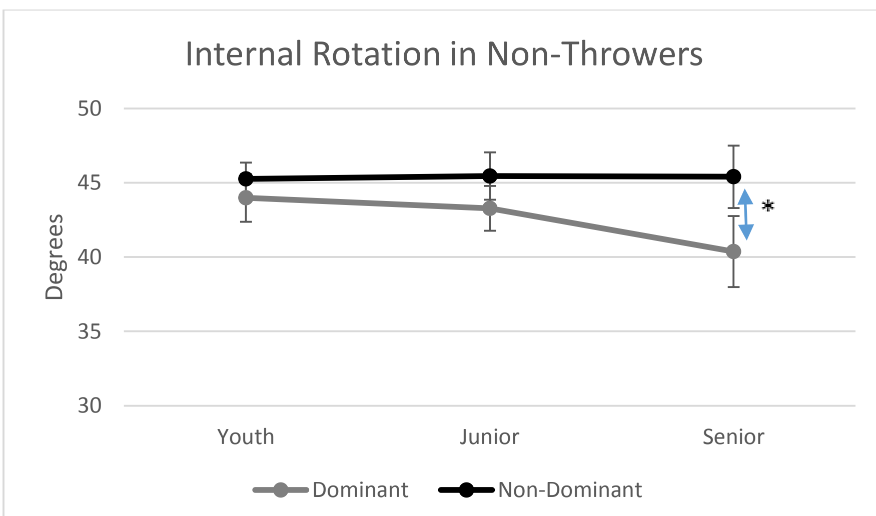
No significant differences in any age group

Figure 4.14- Dominant to non-dominant comparison for internal rotation in throwing group



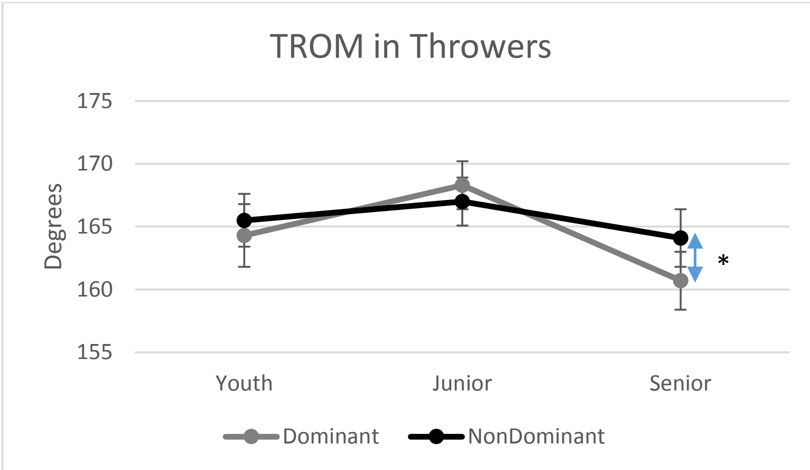
*significant difference (p < .05)
§significant differences (p < .05) between Junior –Senior groups for one-way ANOVA

Figure 4.15- Dominant to non-dominant comparison for internal rotation in non-throwing group



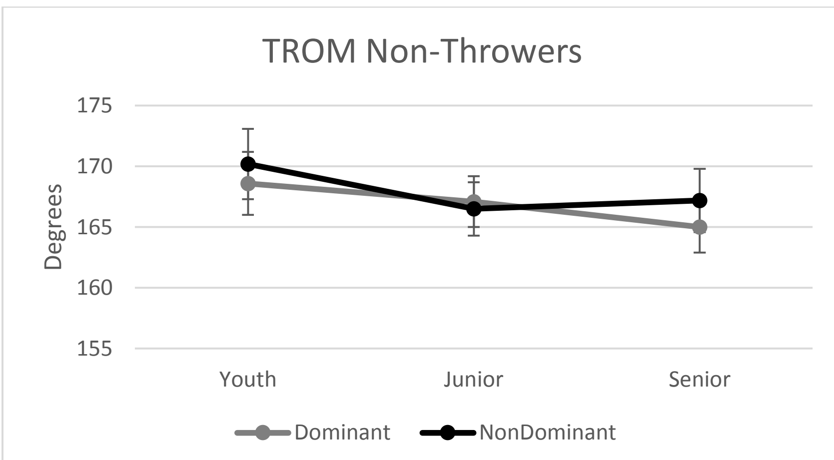
*significant difference (p < .05)

Figure 4.16- Dominant to non-dominant comparison for total range of motion in throwing group



*significant difference (p < .05)

Figure 4.17- Dominant to non-dominant comparison for total range of motion in non-throwing group



Specific Aim 2:

The second aim of this study was to determine the relationship between humeral retrotorsion and clinically measured glenohumeral range of motion.

Analysis Specific Aim 2:

Prior to analysis, scatterplots were generated to visually inspect the data for linearity and screened to ensure it did not violate the assumptions of normality or homoscedasticity. The Pearson correlation coefficient was used to evaluate the strength of the relationship between humeral retrotorsion to glenohumeral external rotation (ER) and internal rotation (IR) in both the dominant and non-dominant arms of throwing and non-throwing groups. Fisher r to z transformation was performed in order to assess if there was a significant difference between correlation values for IR and ER between throwers and non-throwers.

Results Specific Aim 2:

Details of the analysis are presented in Tables 4.24-4.25. Overall, correlations for ER were stronger in the non-thrower groups, while the strength of correlation for IR was higher in thrower groups.

Results indicate that a significant difference in Pearson Correlation Coefficient exists between activity groups for ER in both the dominant and non-dominant arms ($p = 0.002$ for both), but is not significant for shoulder IR ($p = 0.406$ and $p=0.733$).

In summary, our results indicate that the strength of the correlations for shoulder motion and humeral retrotorsion vary based upon direction of motion and activity level. In non-throwing athletes, shoulder ER is more associated with changes in humeral retrotorsion. The opposite can be said for throwing athletes, where shoulder IR is more related to the degree of humeral retrotorsion. This directional relationship remains true for all age and activity groups, and a general trend appears for most variables in which the correlation between humeral retrotorsion and dominant shoulder motion become stronger as these athletes age. (Tables 4.26-4.27)

Table 4.24. Pearson correlation for retrotorsion to shoulder external rotation (activity group comparison)

	Pearson Correlation	p-value	95% CI
Thrower Group (n=85)			
Dominant	0.237	0.029	0.026, 0.428
Non-Dominant	0.214	0.049	0.001, 0.408
Non-Thrower Group (n=68)			
Dominant	0.631	<0.001	0.463, 0.755*
Non-Dominant	0.538	<0.001	0.344, 0.688*

*Statistically significant difference (p=0.002) in correlation coefficients between thrower and non-thrower groups.

Table 4.25. Pearson correlation for retrotorsion to shoulder internal rotation (activity group comparison)

	Pearson Correlation	p-value	95% CI
Thrower Group (n=85)			
Dominant	-0.401	<0.001	-0.565, -0.206
Non-Dominant	-0.416	<0.001	-0.577, -0.223
Non-Thrower Group (n=68)			
Dominant	-0.279	0.021	-0.485, -0.044
Non-Dominant	-0.368	0.002	-0.557, -0.143

No statistical difference between correlations (p=0.406 and p=0.733)

Table 4.26. Pearson correlation for dominant retrotorsion to shoulder external rotation. (age and activity groups analysis)

	Pearson Correlation	**p-value**	**95% CI**
Youth Thrower (n=26)	0.346	0.083	-0.047 , 0.646
Junior Thrower (n=34)	0.120	0.500	-0.227 , 0.440
Senior Thrower (n=25)	0.268	0.196	-0.142 , 0.599
Youth Non-Thrower (n=21)	0.605	0.004	0.235 , 0.822
Junior Non-Thrower (n=27)	0.431	0.025	0.061 , 0.696
Senior Non-Thrower (n=20)	0.796	<0.001	0.546 , 0.915

Table 4.27. Pearson correlation for dominant retrotorsion to shoulder internal rotation. (age and activity groups analysis)

	Pearson Correlation	**p-value**	**95% CI**
Youth Thrower (n=26)	-.0435	0.026	-0.703 , -0.058
Junior Thrower (n=34)	-0.403	0.018	-0.652 , -0.076
Senior Thrower (n=25)	-0.660	<0.001	-0.836 , -0.359
Youth Non-Thrower (n=21)	0.230	0.316	-0.223 , 0.601
Junior Non-Thrower (n=27)	-0.429	0.026	-0.695 , -0.059
Senior Non-Thrower (n=20)	-0.562	0.010	-0.804 , -0.160

CHAPTER 5: DISCUSSION

INTRODUCTION

The focus of this chapter will be on interpreting the findings of the current study and relating them to existing literature. We will discuss the findings related to each of the specific aims and describe the impact of the results on clinical practice. This chapter will conclude with a discussion of study limitations and recommendations for future research.

SPECIFIC AIM #1

The purpose of this study was to evaluate the influence of age and throwing activity on the development of side-to-side differences in humeral retrotorsion and shoulder range of motion (ROM).

Humeral Retrotorsion

As discussed earlier in this manuscript, the final angle of humeral retrotorsion is thought to be the result of 2 factors: a developmental derotation process, and a secondary adaptive torsion caused by muscular forces acting on the humerus.[18,30,33] Sabick et al[30] performed a biomechanical analysis of the forces acting on the proximal humerus during the pitching motion, and concluded that the magnitude and direction of forces is consistent with the development of humeral retrotorsion. At the end of the arm-cocking phase, just before maximum external rotation, overall muscular forces and body acceleration act to create an internal rotation torque at the proximal humerus, while the distal humerus and forearm continue to experience a net external rotation torque until all of the energy is dissipated. (Figure 5.1) In skeletally immature athletes, this net external rotation torque about the long axis of the humerus would likely effect the proximal humeral physis, where mechanotransduction would produce alterations in bony alignment. These stresses would thus facilitate an environment favoring a more posteriorly oriented humeral head, which is consistent with the position of humeral retrotorsion. Authors have theorized that these forces may be sufficient to delay the normal derotation process at the proximal humerus and account for side-to-side differences in humeral retrotorsion.[30] This biomechanical model is consistent with our data, adding to our knowledge of what factors affect the overall degree of humeral retrotorsion present at skeletal maturity. With this understanding of throwing dynamics, it seems that genetic influence, muscular forces that occur with development, and activity-related changes resulting from mechanical forces during throwing are all responsible for the ultimate expression of humeral retrotorsion angle.

Figure 5.1. Diagram of torsional forces during throwing

Figure 5.1 – While pitching, the weight of the forearm and ball act produce an external rotation torsional force about the long axis of the humerus distally (a). Body momentum, joint capsule and muscular forces create an internal rotation torque at the proximal humerus (b). These opposing forces would facilitate a more posteriorly oriented humeral head and consistent with increased humeral retrotorsion.

Until recently, the majority of our understanding of the normal development of humeral retrotorsion was through detailed analysis of cadaveric specimens.[18,32,33] Other authors have assessed humeral retrotorsion in skeletally-immature throwing athletes, and their results have supported the theory that throwing activity causes increased retrotorsion in the dominant humerus, resulting in a larger side-to-side asymmetry.[13,21,22,28,36,81] However, none of these studies included a control group of young non-throwing athletes, instead opting to utilize the non-dominant arm as the controlled comparison group. Theoretically, the non-dominant arm is not subjected to the stimulus of throwing and thus is thought to represent the subject's baseline potential for overall humeral retrotorsion.[13,21,28,81] Although this claim appears valid, there are some weaknesses in this design. If increased humeral retrotorsion in the dominant arm is advantageous to throwing athletes, there could be a tendency for those with higher retrotorsion to gravitate toward throwing activity,[22] thus confounding the results of these prior studies. Without the presence of a true control group, researchers are unable to account for genetic predisposition of humeral retrotorsion levels, the influence of age and the maturation process, and the effect of hand dominance related to general activity on the development of humeral retrotorsion.

Our study is the first to directly compare throwing athletes to a control group of age matched non-throwing athletes. Our results indicate that the activity of throwing may alter side-to-side differences in humeral retrotorsion, with more retrotorsion present in the dominant humerus. Overall, side-to-side differences in humeral retrotorsion are greater for throwing athletes (8.6°) than for non-throwing athletes (4.7°). Our findings show a significant difference between throwers and non-throwers and imply that the act of throwing may impact side-to-side differences in humeral retrotorsion, thus supporting the observations of Sabick et al[30] discussed earlier.

The effect of age on the development of side-to-side asymmetry of humeral retrotorsion is not quite as clear. Our data agrees with previous reports, supporting the notion that humeral derotation occurs with aging.[13,28,30,33] However, prior literature had not been able to establish if the physiological maturation process that occurs with aging was responsible for the development of side-to-side asymmetry in retrotorsion. Thus, although derotation does occur, it is feasible that both humeri would derotate in a symmetrical manner and not account for a side-to-side difference. Although normative studies do indicate that non-athletic adults have a lower degree of side-to-side asymmetry in humeral retrotorsion,[57] this had not been directly studied throughout the pediatric development span.

Our results indicate that aging may be a weak contributor to the development of asymmetry in humeral retrotorsion. This result is not necessarily an effect of the aging process. We believe that this finding likely represents the effect of hand dominance and muscular activity related to increased day-to-day activity utilizing one's dominant arm. Normative studies support this hypothesis, as a small increase in humeral retrotorsion in the dominant arm is normal in a non-athletic adult population.[57] In order to further analyze this relationship, the Pearson correlation coefficient was calculated to determine the correlation between age and change in humeral retrotorsion and side-to-side asymmetry of humeral retrotorsion. Our results revealed a significant but weak negative correlation between dominant ($r = -0.294$, $p=0.006$) and non-dominant ($r = -0.380$, $p=0.000$) humeral retrotorsion and age, indicating that as age increases, humeral retrotorsion tends to decrease. Correlation analysis of age with side-to-side differences in humeral retrotorsion was not significant $r = 0.172$, $p = 0.175$, supporting our finding that age is not responsible for the development of side-to-side asymmetry in humeral retrotorsion.

In summary, humeral retrotorsion does appear to decrease bilaterally as subject age increases, regardless of sports participation. Side-to-side asymmetry in humeral retrotorsion is larger in throwing athletes than in non-throwing athletes, implying that an adaptive response occurs on the dominant side as a result of throwing that cannot be accounted for by age or physiological maturation alone.

Our data support the assertion that the effect of throwing on humeral retrotorsion asymmetry can begin to be seen early on in a child's baseball career. Pairwise comparisons revealed that the dominant arm demonstrates significantly more retrotorsion than the non-dominant arm for all age groups in throwing athletes (Figure 4.10) while the difference in non-throwing athletes is only present in the Junior and Senior groups. (Figure 4.11). Our results are consistent with those of Hibberd et al[13] who noted a similar pattern of significant asymmetry in throwing athletes as young as 8.3 years-old, but differ from Yamamoto et al[28] who did not find significant asymmetry to be present within their group of youth throwers until approximately 11 years of age. Edelson[33] demonstrated that the derotation process that occurs at the proximal humerus happens most rapidly from birth to the age of 8, then slows down through the remainder of skeletal development, ceasing at skeletal maturity. The forces created while throwing act to slow down this derotation process.[30] Thus, it is possible that the forces transmitted through the proximal humerus, by virtue of the activity of throwing during this period of most rapid derotation, could have a more pronounced impact on the development of side-to-side asymmetry in humeral retrotorsion. The fact that our control group did not have significant asymmetry present until they were older strengthens our hypothesis that throwing activity during this period of peak changes might have a large impact in retrotorsion asymmetry. In addition, we can see that the throwing group had a slower progression of derotation in the dominant humerus compared to our control group, who underwent a more rapid degree of derotation between the two youngest age groups.

(Figure 4.10-4.11) After the age of 11, it appears that the humeral derotation process begins to slow down, with significant adaptive changes less likely to occur.

These results lend support to the notion that the younger years are critical for adaptive response to throwing, and consistent with the Yamamoto et al[28] hypothesis that pitching before the age of 11 years-old is more likely to have a greater influence on alteration in bony structure. With the recent shift towards sports specialization in youth athletics, it appears that athletes are beginning to pitch at a younger age and more often. In our current sample, 98.5% of our pitchers began pitching prior to the age of 11. In fact, 51 out of 68 pitchers (75%) began pitching at 8 years-old or younger, and 60.7% of those players were receiving private pitching instruction outside of regular baseball practice. A case can be made that private pitching instruction at a young age can lead to enhanced fundamental skill development required for the pitching motion. However, it is also conceivable that the increased volume of pitching that accompanies private lessons would cause a greater summation of remodeling forces about the proximal humeral physis. Since this occurs during a period of increased susceptibility to changing retrotorsion orientation, it could create an environment that leads to more pronounced adaptive changes in humeral retrotorsion. This extensive and early pitching activity may explain why our sample demonstrated more significant side-to-side asymmetry of humeral retrotorsion compared to other studies of similarly aged athletes.[28,81]

Some authors feel that there may be a “window of opportunity” to develop humeral retrotorsion adaptation that lies within a protective “sweet spot” that is healthy for a throwing athlete. Values outside of this “sweet spot” range may impart an increased risk of upper extremity injury.[24] Our results show that a high level of participation in pitching at a very young age may result in adaptive changes in humeral retrotorsion. This period of life appears to be the time when the proximal physis may be most susceptible to torsional remodeling. Once skeletal maturity is reached, the potential for torsional remodeling at the proximal humeral physis ceases. Thus, a large volume of throwing during the susceptible period may induce excessive bony changes, giving rise to humeral retrotorsion asymmetry outside of the “sweet spot” and leave that athlete more susceptible to injury as an adult.[40,56] Our understanding of how throwing activity as a child determines one’s adult retrotorsion asymmetry is critical, as researchers have identified an association between increased humeral retrotorsion and the development of elbow pain and pathological GIRD in adult pitchers.[40,55,56] Thus, if the youth player is afforded the opportunity to play at an elite level as an adult, it is possible that bony torsion changes that occurred during his younger years could leave him at higher risk of injury as an adult.

Future studies are necessary to more fully understand the degree of influence that throwing volumes or age of initiation of pitching activity have on humeral retrotorsion asymmetry. Our results indicate that retrotorsion derotation becomes affected very early in a baseball player’s life, and in order to truly appreciate these effects, future studies should include players as young as 6 or 7 years-old, prior to the initiation of pitching activity. Studies of this nature would provide an increased understanding of how the introduction of throwing activity modifies the natural history of humeral derotation, which could be used in the development of evidence-based participation guidelines for the most appropriate age to initiate throwing, or revision of current pitch count guidelines.

Both our throwing and non-throwing groups showed a trend for continued humeral derotation with age, on both the dominant and non-dominant sides. This is an important distinction, as previous studies on youth throwing athletes have found that in similar age groups, the dominant humerus did not undergo continued derotation, but mostly remained consistent across age groups.[13,81] This difference may be attributable to variations in throwing activity, including years of throwing experience and volume of throwing activity. The cross-sectional nature of these study designs leaves them vulnerable to this type of limitation and may account for such a difference. For example, in Hibberd et al,[13] the players in each age group demonstrated more years of playing experience and earlier age of participation in baseball than in our sample. This difference was most apparent in the older age groups. Earlier participation and longer duration of throwing activity by the Hibberd sample may have induced larger relative changes in humeral retrotorsion angle, and account for the difference seen in humeral derotation rates across age categories.

SPECIFIC AIM #2:

Shoulder Range of Motion and Relationship to Humeral Retrotorsion

The second aim of this study was to determine the relationship between humeral retrotorsion and clinically measured glenohumeral range of motion.

Our results show that the throwing athletes had a gain of ER (5.2°) and loss of IR (6.0°) in the dominant shoulder, but no asymmetry in shoulder TROM. These findings are in agreement with previous literature which has shown that healthy adult throwing athletes exhibit a pattern of increased glenohumeral ER and limited glenohumeral IR, with symmetrical TROM equal to the non-dominant side.[9-12] It has been suggested that increased humeral retrotorsion may account for this observation,[16,26,27] however, correlational analyses in the published literature appear to be inconsistent and overall not strong.[23,26,27,29,56] Our results indicate that the strength of the correlation between shoulder rotation ROM and humeral retrotorsion varies based upon the direction of motion and throwing activity. Interestingly, we found opposing correlations between our throwing and non-throwing athletes. In the throwing athletes, humeral retrotorsion was more strongly associated with a loss of IR ($r = -0.401$, $p<0.001$) than a gain in ER ($r=0.237$, $p=0.029$), while in our non-throwing groups we found humeral retrotorsion more strongly associated with a gain in ER ($r = 0.631$; $p < 0.001$) than loss of IR ($r = -0.279$; $p = 0.021$).

The published literature examining the correlation of humeral retrotorsion to shoulder ER and IR ROM in skeletally immature athletes is limited. Yamamoto et al[28] reported very weak and non-significant relationships for both ER ($r = -0.043$; $p = 0.733$) and IR ($r = 0.193$; $p = 0.119$) in a group of young throwers with a mean age of 12. Hibberd et al[13] did not perform a direct correlational analysis, but studied the relationship of humeral retrotorsion to age-related changes in shoulder ROM in youth baseball players, using a retrotorsion-adjusted range of motion measurement. In this retrotorsion-adjusted measure, the amount of retrotorsion asymmetry was subtracted from asymmetry in ROM in order to negate the effects of the torsional differences. Using this measure, Hibberd reports that the measurement occurs from a neutral position that will now only vary based upon soft tissue differences. Hibberd found that after accounting for humeral retrotorsion, glenohumeral IR asymmetry remained unchanged across varying age groups, suggesting that a loss of IR during aging is primarily attributed to changes in humeral retrotorsion. Although Hibberd identified bony asymmetry as accounting for all deficits in shoulder IR within their population, this technique of measurement has been criticized because the relationship between humeral retrotorsion changes and shoulder motion is not 1:1, so that an absolute adjustment to the ROM measurement may not be accurate.[56] Our correlation analysis demonstrates that although changes in humeral retrotorsion may be more closely tied to a loss of internal rotation in throwing athletes, this relationship is low to moderate in strength, and there is not an absolute change in IR loss that occurs as a result of altered humeral retrotorsion. Thus our findings support the criticism of utilizing this absolute correction methodology, and we believe that the conclusions of Hibberd et al should be interpreted with caution.

Our results are in agreement with other recent literature that indicates humeral retrotorsion has a stronger influence on IR than on ER motion in throwers.[16] Since a loss of IR ROM is an identifiable risk factor for upper extremity injury in throwing athletes,[68,70,71,82] understanding what elements contribute to this loss of motion is critical. Assessment of humeral retrotorsion may help increase our understanding of bony influence on IR ROM loss in throwing athletes. This knowledge may aide in rehabilitation program design by identifying those athletes that are in need of intervention. If the main contributor to dominant shoulder IR loss is humeral retrotorsion, interventions aimed at improving soft tissue mobility would be unwarranted. However, if soft tissue was accounting for this loss of motion, targeted interventions for stretching or mobilization would now be appropriate. Thus, an understanding of that individual throwing athlete’s retrotorsion asymmetry would assist with advanced clinical decision making. In addition, knowledge of a throwing athlete’s retrotorsion asymmetry may help identify athletes who are at a higher risk of developing pathological IR loss, which may result in an increased injury potential.

Although statistically significant, the correlation between ER and humeral retrotorsion was weak in throwers which implicates soft tissue contributions are highly important accounting for glenohumeral ER ROM. It has been proposed that adaptive changes such as anterior capsular laxity may account for increasing ER ROM in the dominant arm of throwing athletes,[68] and our low correlation values for ER and humeral retrotorsion do indicate that bony factors do not exert a major influence on shoulder ER within the youth throwing population. In addition, correlation values on the non-dominant side of the same athletes exhibit the similar pattern of stronger correlation to IR loss rather than ER gain. This may indicate that young athletes with a natural ability to obtain the necessary degree of ER necessary to excel at throwing a baseball by other means (such as capsular laxity or muscular flexibility) may gravitate towards throwing sports.

It has been suggested that humeral retrotorsion could improve throwing velocity via improving one's ability to achieve greater degree of shoulder ER, which would allow for greater arm movement in the acceleration phase of throwing, leading to increased ball velocity at ball release.[19,55] Our results indicate that although humeral retrotorsion may be increased on the dominant side, it may not directly relate to an increase in glenohumeral ER motion, and this finding questions the mechanism of performance enhancement with increased ball velocity related to humeral retrotorsion. In summary, while an increase in humeral retrotorsion may provide some protection from injury during the cocking phase of throwing,[24] it may not result in enhanced performance or ball velocity while throwing via a direct increase in ER. Future studies evaluating the relationship of humeral retrotorsion and its effect on shoulder ROM and performance factors are necessary to provide further insight into this situation.

To our knowledge, we are the first to analyze the relationship of humeral retrotorsion to ROM changes in young non-throwing athletes. It is an interesting and unexpected finding that there was such a stark contrast between throwing and non-throwing athletes. While we are not certain what is responsible for this divergence in correlational relationship between activity groups, our results indicate that there is some type of soft tissue adaptation that occurs as a result of throwing activity which alters the interaction between bony changes and shoulder rotation motion. In addition, we stratified our activity groups by age and found that the correlation directionality remains fairly consistent, however, there is a general trend for the correlations to grow stronger with age. This may indicate that as these athletes age and the rate of change in humeral retrotorsion becomes slower, shoulder rotational motion may become more closely associated with the bony configuration. While our analysis appears to bring forth many questions, we feel that these results do provide further insight into the dynamic interaction of bony torsional influence on shoulder ROM within the developing athlete. Longitudinal studies within the youth population are necessary in order to more fully understand this relationship and help determine the true influence of changes in humeral retrotorsion on shoulder ROM.

LIMITATIONS:

There are several limitations to our study that warrant acknowledgement. There was no standardized warm-up prior to assessment of shoulder ROM. Range of motion measurements may be affected by tissue temperature or level of activity prior to examination. All of our measurement procedures took place on-field / on-site as part of an athletic event, and practical limitations of time did not allow for a separate and standardized warm-up. However, all throwing athletes were actively engaged in baseball activity at the time of assessment, and had undergone team specific warm-up prior to their involvement in our study, so that tissue was likely preconditioned to a proportionate level across all measurement sessions. In the case of our non-throwing athletes, they were actively participating in sports-related activity that involved some degree of aerobic activity prior to measurement. Their activity was not throwing-specific, and this could introduce some variation in shoulder ROM measurements, however, we feel that this variation would be small and that the general global warm-up that accompanies cardiovascular activity would provide sufficient elevation in tissue temperature for adequate preconditioning prior to the measurements.

Since baseball is one of the most popular youth sports in America,[1] it is extremely difficult to find young, athletic individuals that have never participated in any baseball activity. We attempted to control for this by requiring that all subjects included as non-throwers had not played any organized baseball for at least the last calendar year. In addition, we collected data on any non-throwers that had played baseball identifying the level and amount of baseball activity that was played, so that we could include this information for sub-analysis.

This was a cross-sectional study that looked at players at one time in their playing career and thus playing exposure could not be fully accounted for. The volume of throwing experienced by the thrower group was indirectly quantified by number of months per year and number of teams they played for. We did not have direct assessment of number of throws performed for several reasons. Typically, volume of throwing during baseball competition is quantified through pitch counts. At the youngest age bracket (8-10 years), many players have not yet become specialized into pitchers or field players only. Thus, pitch count is not a practical consideration within this group, as most throwing is performed in practice situations and field work. In addition, collection of this type of data presented many practical issues related to attempting to quantify pitch counts through parent / player recollection, and to participation in multiple leagues and practice scenarios.

Another limitation is that there was no direct measure of physiological maturity. We utilized chronological age to group our subjects, but due to differences in physiological maturation in young individuals, this may not directly relate to the degree of skeletal maturity. Future studies may consider the use of more precise measures of physiological maturity (Tanner staging or skeletal age via plain radiographs) in order to more precisely define skeletal maturity.

Our sample included only healthy male individuals that were currently participating in sports activity. Thus, our results cannot be generalized to females, or to an injured population. In addition, our groups were not equally sized. This may have impacted our statistical analysis, however we feel that this impact was minimal.

Finally, we would like to note that the cross-sectional study design we utilized is vulnerable to selection bias, as older players are likely to be more specialized than younger players.

DELIMITATIONS

The degree of humeral torsion can be affected by factors related to injury, such as proximal humeral fracture or muscular paralysis. This was accounted for by the exclusion criteria ensuring that there was no history of fracture or neurological disorder in any subject. Additionally, humeral torsion can be asymmetrically affected by other unilateral or overhead sports activity, such as tennis or squash, and swimming.[22] All subjects enrolled in the non-thrower group were surveyed on their athletic activities, and excluded if they participated in these sports.

In order to ensure that shoulder ROM was not disproportionately affected, individuals with Ehlers-Danlos syndrome or any other congenital disorder that may affect soft tissue were excluded from participation.

Using ultrasound to measure humeral torsion is skill-dependent and may be less reliable in novice sonographers. The investigators underwent formal training and extensive practice sessions prior to engaging in this study. A reliability study was conducted and the investigators were found to have excellent inter and intra-rater reliability. However, variations in humeral head / bicipital groove morphology between individuals of varying age groups can introduce additional variability in the required anatomical landmarks for measurement, and may lessen the overall reliability of this technique. This variation was accounted for within our measurement protocol by utilizing specified features of the bicipital groove, which would limit the confounding effect of this consideration.

SUMMARY

Humeral torsion is defined as the rotational difference in the relative position of the humeral head and the axis of the elbow at the distal humerus.[18,19] Humeral retrotorsion describes the bony architecture that occurs when the head of the humerus is oriented in a posterior medial direction, and is associated with a transverse plane rotation within the humerus. At birth, the humeral head is in marked retrotorsion and undergoes a process of derotation (less retrotorsion) during the pediatric and adolescent years.[18,33] The final amount of humeral retrotorsion is likely determined by 2 factors: a genetically-determined developmental derotation process, and a secondary adaptive torsion brought about by muscular forces acting on the humerus and causing reactive adaptation.[18,30,33] Several investigations have consistently noted an increase in humeral retrotorsion, in the dominant shoulder of throwing athletes.[10,20-26] It is believed that the forces involved in overhead throwing cause a slowing of the natural derotation process that occurs, resulting in a higher degree of side-to-side asymmetry in humeral retrotorsion upon skeletal maturity.[30] However, studies involving the youth population are limited and it is not currently clear at what point these side-to-side asymmetries develop, or whether humeral retrotorsion is directly impacted by throwing activity and volume.

The significance of this observed alteration in humeral alignment and its relationship to injury is currently not clear. Many authors propose that this alteration represents a healthy adaptation to the stress of the throwing motion, allowing for increased overall arm external rotation with reduced stress to the glenohumeral joint soft tissue.[9,20,24,36] Such an adaptation may therefore have a protective effect against injury. However, there is also evidence that insufficient or excessive humeral torsion may actually contribute to injury in the shoulder or elbow, either through direct interaction of bony alignment on soft tissue stress, or by virtue of the effect that humeral retrotorsion has on clinical shoulder ROM.[24,40,56]

In order to address some of these questions we conducted a cross-sectional matched group study utilizing two groups of youth athletes aged 8 to14 years-old that differed in sports participation. One group consisted of athletes who specialized in baseball, with participation in baseball greater than 6 months per year. The control group consisted of age- and activity-matched individuals that either had no history or very limited history of baseball participation. All subjects and parents/guardians reviewed and signed assent and consent forms that were approved by all participating Institutional Review Boards. Subjects provided demographic information and completed a customized sports participation and injury form (Appendix G). Bilateral measurements were performed for all subjects. Humeral retrotorsion was measured using ultrasound with a previously described and validated technique.[21,28,49] In addition, glenohumeral range of motion for ER and IR were assessed at 90° elevation using a digital inclinometer. Side-to-side asymmetries were calculated for all variables by subtracting the non-dominant value from the dominant side value (dominant minus non-dominant = side-to-side asymmetry). Shoulder rotational strength and pitching velocity were also collected for use in a subsequent analysis.

The subjects were stratified into three different age categories: Youth (8-10.5), Junior (10.51-12) and Senior (12.01-13.99). A two-way analysis of variance was performed with throwing status (yes/no) and age group as the primary factors, and side-to-side asymmetry in: humeral retrotorsion, glenohumeral ER ROM, glenohumeral IR

ROM and TROM, as the dependent variables. Paired-samples t-tests were utilized to analyze differences in humeral retrotorsion, glenohumeral ER, glenohumeral IR and TROM between the dominant and non-dominant sides within the respective activity groups. In addition, Pearson product correlation coefficients were utilized to analyze the relationship between humeral retrotorsion and shoulder ROM.

We determined that the activity of throwing causes a larger degree of humeral retrotorsion to be present on the dominant side, and results in greater side-to-side differences for throwing athletes (8.6°) than for non-throwing athletes (4.7°). Although age was associated with decreasing humeral retrotorsion, the aging process in and of itself does not have a large influence on the development of side-to-side asymmetry. In terms of shoulder ROM, we found that the throwing athletes had a gain of ER (5.2°) and loss of IR (6.0°) in the dominant shoulder, relative to the non-dominant shoulder, but no change in asymmetry in shoulder TROM. The effects of age on shoulder ROM were minimal, however, there was a significant loss of IR ROM that occurred with age (3.9°), indicating that there may be some additive effect of age/maturation that may contribute to the observed loss of shoulder IR ROM in youth throwing athletes.

Pairwise comparisons of each activity group revealed that the throwing athletes demonstrated significant side-to-side asymmetry in humeral retrotorsion within each age category, while the non-throwing athletes did not develop significant asymmetry until they were older. This result indicates that the adaptive changes in humeral retrotorsion that occur as a result of throwing begin to occur very early in youth throwing athletes, likely before 8 years of age. Range of motion comparisons revealed that significant differences in glenohumeral ER and IR existed between all age groups for the throwing athletes, while we observed no differences in our control group until the oldest group, in which there was only a difference in IR ROM. This demonstrates that there are adaptations in clinical ROM measurements that may occur at a young age within throwing athletes.

We utilized the Pearson correlation coefficient in order to analyze the effect that changes in humeral retrotorsion have on glenohumeral ER and IR ROM. Our results indicate that the strength of the correlations for shoulder motion and humeral retrotorsion vary based upon direction of motion and activity level. In non-throwing athletes, shoulder ER is more associated with changes in humeral retrotorsion, whereas in throwing athletes shoulder IR is more related to the degree of humeral retrotorsion. This directional relationship remains true on the non-dominant side as well.

In conclusion, our results clearly illustrate that throwing activity causes adaptive changes in humeral retrotorsion and shoulder range of motion in children at a very young age. Although physiological maturation does contribute to the process of humeral derotation, the effect of this factor is not a major contributor to the development of significant side-to-side asymmetries. The relationship between changes in bony torsion and shoulder range of motion is complex. Our data indicates that humeral retrotorsion may exert a stronger influence on shoulder internal rotation range of motion in throwing athletes. Due to the link between a loss of internal rotation and risk of throwing arm injuries, clinical knowledge of humeral retrotorsion angle would be helpful for injury rehabilitation and injury prevention programming in youth athletes.

APPENDIX A

LETTER OF SUPPORT

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Philadelphia, PA 19104

Dear Colleagues:

I am pleased to support the application of Elliot Greenberg, PT, DPT as a Legacy Fund applicant through the Sports Section of the American Physical Therapy Association. Dr. Greenberg is a PhD candidate at Nova Southeastern University who will be the principal investigator. He will work along with Philip McClure PT, PhD, FAPTA who is a full professor at Arcadia University who will serve as a mentor on the project. I expect that this grant will support the start of Dr. Greenberg's research career and support the completion of his doctoral degree.

By receiving this grant, Dr. Greenberg would acquire knowledge in determining the effects of throwing activity and age on humeral torsion and glenohumeral ROM in the pediatric and adolescent population which will be an important contribution to the physical therapy sports medicine literature.

Dr. Greenberg has a strong clinical and research relationship with the orthopedic physicians here at The Children's Hospital of Philadelphia which will support this project and allow him to conduct future research projects with the patient population here at CHOP. CHOP is an excellent environment for researchers and with the formal relationship we have with Arcadia University's Department of Physical Therapy will certainly foster Dr. Greenberg's development as a researcher and support completion of his doctoral work and this project specifically.

In summary, we are willing to support Dr. Greenberg in receiving this grant and completing this research project which is in line with our department's research plan. If Elliot is provided this opportunity to receive this grant, the knowledge and experience he will gain will certainly allow him to contribute to our department's research agenda.

Thank you,

Kim Nixon-Cave, PhD, PT, PCS

APPENDIX B

ARCADIA IRB APPROVAL

ARCADIA UNIVERSITY

Committee for the Protection of Research Subjects
450 S. Easton Rd.
Glenside, PA 19038
INSTITUTIONAL REVIEW BOARD
(Federalwide Assurance # 00000449)

April 25, 2014

Protocol #: 14-03-16
PI: Greenberg
Title: Humeral Torsion in Developing Children and its relationship to Throwing Sports

Dear Dr. Greenberg,

Thank you for submission of the requested revisions to the above-referenced Protocol, following Full Board Committee Review by Arcadia University's Institutional Review Board (IRB). Approval was issued on **April 25, 2014** for 3 year. This approval expires on **April 25, 2017**. This letter constitutes official notification of the Approval, and you are authorized to commence the research as of the date of Approval.

Under the provisions of Arcadia University's Federal-Wide Assurance for compliance with the Department of Human Health Services Regulations, the principal investigator is directly responsible for submitting to the IRB any change in the research. Note: All changes must be reviewed and approved by the Committee prior to implementation. Unanticipated, unusual, unexpected hazards or adverse events involving risk to the subject or others must be reported immediately to the Committee giving detail and your assessment of the occurrence.

Note that the Board recommends submitting renewal/continuation applications 90 days prior to expiration in order to allow adequate time for review. **A Progress Report is due annually on the anniversary date of approval or the protocol will automatically be terminated, and a Termination Report will be due at the close of the study.** We wish you the best in your research endeavors.

Sincerely,

Scott Stackhouse, PhD
Chair, Arcadia University Institutional Review Board
Chair, Arcadia University Committee for the Protection of Research Subjects

TEL: 215.572.2900 WWW.ARCADIA.EDU
450 S. Easton Road, Glenside, PA 19038-3295
WISDOM TO GROW ON, WORLDS TO EXPLORE

APPENDIX C

NOVA SOUTHEASTERN UNIVERSITY IRB APPROVAL

NOVA SOUTHEASTERN UNIVERSITY

MEMORANDUM

To: Elliot Greenberg, B.S., DPT
HPD – College of Health Care Sciences

From: David Thomas, M.D., J.D. [signature]
Chair, Institutional Review Board

Date: July 15, 2014

Re: *Humeral Torsion in Developing Children and its Relationship to Throwing Sports* – NSU IRB No. 06051406Exp.

I have reviewed the revisions to the above-referenced research protocol by an expedited procedure. On behalf of the Institutional Review Board of Nova Southeastern University, *Humeral Torsion in Developing Children and its Relationship to Throwing Sports* is approved in keeping with expedited review category # 4 and #7. Your study is approved on **July 10, 2014** and is approved until **July 9, 2015**. You are required to submit for continuing review by **June 9, 2015**. As principal investigator, you must adhere to the following requirements:

1) CONSENT: You must use the stamped (dated consent forms) attached when consenting subjects. The consent forms must indicate the approval and its date. The forms must be administered in such a manner that they are clearly understood by the subjects. The subjects must be given a copy of the signed consent document, and a copy must be placed with the subjects' confidential chart/file.

2) ADVERSE EVENTS/UNANTICIPATED PROBLEMS: The principal investigator is required to notify the IRB chair of any adverse reactions that may develop as a result of this study. Approval may be withdrawn if the problem is serious.

3) AMENDMENTS: Any changes in the study (e.g., procedures, consent forms, investigators, etc.) must be approved by the IRB prior to implementation.

4) CONTINUING REVIEWS: A continuing review (progress report) must be submitted by the continuing review date noted above. Please see the IRB web site for continuing review information.

5) FINAL REPORT: You are required to notify the IRB Office within 30 days of the conclusion of the research that the study has ended via the IRB Closing Report form.

The NSU IRB is in compliance with the requirements for the protection of human subjects prescribed in Part 46 of Title 45 of the Code of Federal Regulations (45 CFR 46) revised June 18, 1991.

Cc: Dr. M. Samuel Cheng
Dr. Philip McClure
Mr. Randy Denis

Institutional Review Board
3301 College Avenue • Fort Lauderdale, Florida 33314-7796
(954) 262-5369 • Fax: (954) 262-3977 • Email: irb@nsu.nova.edu • Web site: www.nova.edu/irb

APPENDIX D

FACILITY OR LEAGUE AGREEMENT FORM

Facility / League Agreement Form

I am writing this letter seeking your support, to conduct a research study with athletes at your facility. Participation would be completely voluntary from the athletes (and parents) involved in your program. We (Dr. Elliot Greenberg and Dr. Phillip McClure) are conducting a research study seeking to help us better understand the effects of sports participation on the shoulder of young athletes. The primary objective of this study is to use ultrasound (like that used in pregnancy) to investigate humeral torsion (twisting of the upper arm bone) and shoulder rotation range of motion across an age spectrum of young athletes with different throwing histories. The secondary purposes of our study are to determine if a relationship exists between bony structure, joint range of motion, shoulder muscle force and throwing velocity. The long term goal of our work is to better understand shoulder problems associated with throwing athletes and this study would move us closer toward understanding injury mechanisms. This study protocol has been approved by the Arcadia University Internal Review Board.

In order to be included in this study, we are seeking athletes ranging in age from 8-14 years and participate in baseball <u>either</u> less than one (1) month <u>or</u> greater than six (6) months of the year. The measurements involved within this study are not dangerous or painful. We will come to your athletic field/center to collect data so there will be minimal loss of time from practice for any athlete that participates. The entire data collection process will take approximately 10 minutes and participants will receive a $10 gift card for volunteering. If you are amenable, we will work with you to determine logistical details of acquiring the required parent/guardian consent and youth assent to participate in the study.

We expect that the information gained from this research study will help us better understand the complexity of the athletes' shoulder and improve our recognition of injury risk factors. If you support the above outlined project and are willing to allow us to solicit the participation of your athletes and parents please sign below. Thank you.

____ ___________

Representative Signature Date

____

____

____

Name and Address of Facility or Organization

APPENDIX E

PARENTAL CONSENT FORM

Parental/Guardian Consent to allow a child participation in a research study

Title of Research: Humeral Torsion in Developing Children and its Relationship to Throwing Sports

Arcadia University IRB protocol #14-03-16
Nova Southeastern University IRB protocol #06051406Exp

Investigators:

Elliot Greenberg, PT, DPT, OCS, CSCS; Adjunct Faculty, Arcadia University

Philip McClure PT, PhD; Professor of Physical Therapy, Arcadia University

Alicia Fernandez-Fernandez PT, PhD; Professor of Physical Therapy, Nova Southeastern University

Background and Purpose of Research:

Your child is being asked to participate in a research study. The primary purpose of this study is to use ultrasound (similar to the type of machine used see the baby in women during pregnancy) to investigate humeral torsion (twisting of the upper arm bone) and glenohumeral (shoulder) rotation range of motion (ROM) across an age spectrum (8-14) of young athletes with different throwing histories. Specifically we plan to determine the effects of *throwing activity* and *age* on humeral torsion and glenohumeral ROM. The secondary purposes of this study are to determine if a correlation exists between bony structure and glenohumeral joint range of motion, shoulder muscle force, or throwing velocity.

Inclusion/Exclusion Criteria

Your child is eligible to participate in this study if they meet all of the following criteria:

- They are male
- They participate in baseball either less than 1 month/year or more than 6 months per year
- They can lift their arms to a 90 degree angle to their body
- They have no history of humeral fracture

- They have no history of shoulder trauma such as fracture, dislocation or surgery within the past 3 months
- They have no known connective tissue disorder

Procedures and Duration

All examination procedures will be performed by Dr. Greenberg or Dr. McClure, as well as appropriately trained physical therapists or physical therapy students. We will first ask you and your child to complete a brief survey asking age, height, weight as well questions related to their sports activity and shoulder function. Participants will be asked to remove their shirts and lay on their backs on a treatment table. Their arm will be positioned in such a way so that it is at a 90 degree angle from the body. An examiner will then rotate the shoulder in order measure how far the shoulder can rotate outward or inward. This position will be measured using an electronic device placed against the forearm. After this measurement is complete, an examiner will place gel on your child's shoulder and then apply an ultrasound probe onto their skin. At this point a projection of the ultrasound image will be displayed on a screen. The examiner will then rotate your child's shoulder through a small range, in order to find the proper position for measurement. Once this position is determined, the arm will be held still, while a second examiner places an electronic device on your child's forearm in order to measure the angle. The entire procedure will then be repeated on the opposite side. Next, in the same position, we will measure shoulder muscle force on both arms by asking your child to push as hard as they can against a stationary measurement device. In addition to these measures, we will also measure throwing velocity using a radar gun. After 5-10 warm-up throws, your child will be asked to throw as hard as they can, three times at a target 46 feet away. The entire procedure should be completed in about 20 minutes.

Protection of Subjects

All subjects will be assigned a non-identifying subject number. These numbers will be used in place of names in all reports. Only the investigators will know the identity of the subjects. The information gained from this study may be presented to Arcadia University faculty, at professional meetings, or in professional publications. No individual identities will be revealed in any publications. No information related to our measurements will be shared with the coaching staff, however because data collection will occur at practice, teammates and coaches may be aware of who participates in the study. All data will be recorded electronically and stored on a password protected computer while hard copies of data sheets will be kept in a secure cabinet in the investigators office. Upon completion of this study and subsequent publications, data will be kept for a period of three (3) years and then discarded.

Potential Risks and Discomforts

There are no serious risks associated with this research. It is possible that your child may experience some minor discomfort with positioning of the shoulder during testing or while throwing. If this occurs you or your child can request to stop the measurement.

Additionally, your child will be asked to off his shirt for the measurement process. It is possible that this may make him feel uncomfortable.

Special Precautions to Minimize Risk or Discomfort

The inclusion/exclusion criteria are designed to minimize the potential that any participant will have discomfort during the testing procedure.

Benefits

There are no direct benefits from participation in this study. The information gained through this study may lead to improved understanding of injury dynamics in future research studies. The researchers are only using ultrasound to identify a bony landmark. We will not be able to make a diagnosis or identify any abnormalities that may be present in your child's shoulder.

Voluntary Participation

You understand that your child's participation in this study is completely voluntary and that you or they may stop their participation at any time without penalty by simply informing one the investigators you would like to stop. If your child withdraws after some data is collected, any data collected up to that point may be used based on the discretion of the researchers.

Subject Compensation

Upon full completion of all measurements, your child will be given a $10 gift card to acknowledge the time and inconvenience associated with participation.

Contact for Questions

This study has been approved by the Arcadia University and Nova Southeastern University Institutional Review Boards (IRB). To ensure that this research continues to protect your rights and minimizes your risk, the IRB reserves the right to examine and evaluate the data and research protocols involved in this project. If you wish additional information regarding your rights in this study you may contact the Arcadia University Office for the Committee for the Protection of Research Subject at 267-620-4111 or Nova Southeastern University Human Research Oversight Board at 954-262-5369.

If you have any questions about the study, you may contact:

Elliot Greenberg PT, DPT, OCS at 215-716-3689 or greenbee@arcadia.edu
Arcadia University 450 S. Easton Road, Glenside, PA 19038

Philip McClure, PT, PhD at 215-572-2863 or mcclurep@arcadia.edu
Arcadia University 450 S. Easton Road, Glenside, PA 19038

Alicia Fernandez-Fernandez PT, PhD at 954-262-1653 or alicfern@nova.edu
Nova Southeastern University 3200 South University Drive, Fort Lauderdale, FL 33328

Consent Statement

I have been informed of the reasons for this study and voluntarily consent to participate. I have read the consent form and have been given a copy of this consent form for my personal records.

____ ____________________

Parent/Guardian (signature) Date

____

Parent/Guardian (printed name)

____ ____________________

Investigator or Individual obtaining this consent (signature) Date

____

Investigator or Individual obtaining this consent (printed name)

APPENDIX F

CHILD ASSENT FORM

Assent Form for Children Under 18

Title of Research: Humeral Torsion in Developing Children and its Relationship to Throwing Sports

Arcadia University IRB protocol #14-03-16
Nova Southeastern University IRB protocol #06051406Exp

Investigators: Elliot Greenberg, PT, DPT, OCS, CSCS
Philip McClure, PT, PhD
Alicia Fernandez-Fernandez, PT, PhD

Who are we and what are we looking to do?

I am Dr. Elliot Greenberg. My co-workers, and I are asking if you would like to participate in a research study that we are conducting. We are interested in seeing how the shape of your arm bone and shoulder function is affected by your sports activity.

Why are we doing this study?

Kids who play sports sometimes have shoulder problems. We are doing this research to better understand how this might happen.

What will happen to me if I am involved in this study?

We will first ask you to answer some questions about your sports activity. Next we will have you lay down on your back with your arm out to the side. Then we will measure how far your shoulder can rotate. Then, one of us will place a small ultrasound probe onto your shoulder, which will project an image of your bone onto a computer screen. We will then move your arm back and forth slightly in order to get into the proper position. When we find this position, we will hold your arm steady and measure the angle of your forearm. After this is finished, we will do the exact same thing on the other side. Then, we will measure your shoulder strength by asking you to push as hard as you can into a small device. Also we will see how fast you can throw a ball by asking you to throw as hard as you can 3 times while we measure with a radar gun. This all should take about 20 minutes.

Is any part of this study dangerous?

No, ultrasound and the other measures are very safe.

Will any part of the study hurt?

It is possible that you can feel some mild pain while lying in the testing position, we do not expect anyone to feel any pain but if you do, just tell us and you can stop right away. Also, while taking the measurement we will ask you to remove your shirt. This may make you feel uncomfortable.

Do I get anything for being in this study?

If you complete all the measurements, you will get a $10 gift card.

Do I have to be in this study?

No you don't. Your participation is completely voluntary. If you decide to participate but then would like to change your mind, it is no problem. We will stop the measurement at any time if you simply tell us to stop.

Who will know that I am in the study?

Only the people taking the measurements and your parents will know that you are in the study. However, since we will be taking measurements in a public place, it is possible that others may see you while participating. All of your measurements will be kept secret and we will not tell anyone anything you tell us.

Do you have any questions?

You can ask questions at any time. You can ask now or later. You can talk to me, Dr. McClure or Dr. Fernandez-Fernandez at any time. Here is how to reach us:

Dr. Elliot Greenberg 215-716-3689 or greenbee@arcadia.edu
Arcadia University 450 S. Easton Road, Glenside, PA 19038

Dr. Philip McClure at 215-572-2863 or mcclurep@arcadia.edu
Arcadia University 450 S. Easton Road, Glenside, PA 19038

Dr. Alicia Fernandez-Fernandez at 954-262-1653 or alicfern@nova.edu
Nova Southeastern University 3200 South University Drive, Fort Lauderdale, FL 33328

If you would like to speak to someone at Arcadia University you can call 267-620-4111 or if you would like to speak with someone at Nova Southeastern University you can call 954-262-5369.

Would you like to be this study?

_____ **Yes, I would like to be in this study.**

_____ **No, I don't want to be in this study.**

____ ___________

Sign your name here Date

____

Print your name here

____ ___________

Investigator Date

APPENDIX G

SPORTS PARTICIPATION AND INJURY SURVEY FORM

For examiner use:

Subject ID ________

Sports and Symptom Survey Form

Name ____
Age:___ **Date of Birth: ____/____/______** **Height____________**
Weight _____

What arm do you use to throw? _____ Right _____Left

What sports do you <u>currently</u> play <u>competitively</u> in a league or organization?

<u>Type of Sport</u>:	**<u>Age when you began playing</u>?**	**<u>Months per year you practice</u>?**
1. _______________	__________________________	____________________
2. _______________	__________________________	____________________
3. _______________	__________________________	____________________
4. _______________	__________________________	____________________

Have you **<u>ever</u>** played competitive baseball? Yes or No (Circle One)

*If yes, from what ages did you play? ________________

Do you **<u>currently</u>** play competitive baseball? Yes or No (Circle One)

<u>Baseball Players</u>: (if not currently playing baseball, skip this section and go to the next page)**

How old where you when you began playing baseball? _______________

Over the past year, how many months have you played baseball? ___________

Do you play for more than one league? Yes or No (circle one)

Do you pitch? Yes or No (circle one)

*If yes, how old were you when you began pitching? ________

*Have you ever had private pitching instruction? ___________

For examiner use:
Subject ID ________

Have you had any **shoulder** pain in the past month?

_______ No
_______Yes
*If yes, which arm? _____Left _____Right _____Both

Have you had any **elbow** pain in the past month?

_______ No
_______Yes
*If yes, which arm? _____Left _____Right _____Both

Do you currently, or have you ever had any of the following shoulder problems?

	No	Left	Right	If yes, when did this occur?
Shoulder Dislocation				
Fracture (Broken Bone) in shoulder or collar bone				
Other Shoulder problem? Explain:				

Symptoms and Functional Ability

The following questions relate to the impact of any shoulder problem you may have on playing your sport. Please circle the number that best describes your physical ability **in the past month**. Did you have any difficulty:

	No difficulty	Mild difficulty	Moderate difficulty	Severe difficulty	Unable
1. Using your usual technique for playing your sport	1	2	3	4	5
2. Playing your sport because of shoulder pain	1	2	3	4	5
3. Playing your sport as well as you would like	1	2	3	4	5
4. Spending your usual amount of time playing or practicing your sport	1	2	3	4	5

APPENDIX H

DATA COLLECTION FORM

Name:

Age:

Dominant Arm: (circle one) Left Right

Official Use Only Subject ID: Date:

Shoulder Range of Motion:

	ER @ 90°		IR @ 90°	
	Test 1	Test 2	Test 1	Test 2
Right				
Left				

***** Must have + or – Sign associated with ER @ 90 *****

Humeral Retroversion:

	Test 1	Test 2	Test 3
Right			
Left			

(Note: Negative sign indicates on IR side of 90°)

Shoulder Strength

	ER @ 90°		IR @ 90°	
	Test 1	Test 2	Test 1	Test 2
Right				
Left				

Throwing Velocity

Trial 1		Trial 2		Trial 3	
Peak	Plate	Peak	Plate	Peak	Plate

APPENDIX I

LEGACY FUND GRANT AWARD LETTER

March 19, 2014

Elliot Greenberg PT, DPT, OCS, CSCS
Arcadia University Department of Physical Therapy
450 S. Easton Road, Glenside, PA

Dr. Greenberg;

The review committee for the Sports Physical Therapy Section's Legacy Fund has completed its review of your grant application titled "*Humeral Torsion in Developing Children and its Relationship to Throwing Sports*". On behalf of the review committee and the Sports Physical Therapy Section of the American Physical Therapy Association, I am pleased to inform you that your application has been recommended for funding in the amount of $5,000.00.

We must receive 4 things prior to sending out your funds for this grant:

1.) a copy of the IRB approval letter from your institution's human subjects research internal review board,
2.) a copy of the IRB-approved consent form,
3.) a copy of the **submitted budget** from your grant proposal *and* if you have a 2 year grant a copy of your budget broken down into Year 1 and Year 2,
4.) a 300 word maximum summary abstract in lay language that will be used by the Orthopaedic Section to describe your grant.

ALL INFORMATION MUST BE RECEIVED NO LATER THAN May 1, 2014 OR YOUR GRANT APPLICATION WILL BE DISQUALIFIED. Please take note of the attached Agreement Form and the requirements for release of grant funding. You may e-mail or send via mail the Agreement Form to the Section Office:

Attn: Mark DeCarlo, Executive Director
Sports Physical Therapy Section, APTA
9002 N Meridan, Ste 112A
Indianapolis, IN 46260

If you have any questions, please do not hesitate to contact me. Congratulations on your successful application and best of luck in executing this project!

Sincerely,

Charles A Thigpen PhD, PT, ATC

Chuck Thigpen, PhD, PT, ATC
Chair, Research Committee

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