ADAPTATIONS OF THE SHOULDER TO OVERHEAD THROWING IN YOUTH ATHLETES

by

Matthew M. Astolfi

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Masters of Science in Exercise Science

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ABSTRACT

Introduction: Due to the high repetition and force associated with overhead throwing anatomical adaptations are observed in elite and professional level baseball athletes however, little is known about their origin and progression. This is especially concerning because the incidence of chronic shoulder injuries in youth baseball is on the rise and may precipitate lifelong biomechanical alterations and associated pathologies. Arm dominance and throwing have been correlated with structural changes in older throwers including humeral retroversion (HR), and posterior capsule thickness (PCT) yet the influence of age on these adaptations is unknown. *Purpose:* To investigate the relationship of age and arm dominance on measures of HR, PCT, subacromial space (SAS), glenohumeral internal rotation (GHIR), external rotation (GHER), posterior shoulder tightness (PST). *Methods:* Thirty-five subjects ages eight to twelve years old, participating in organized youth baseball underwent testing using Diagnostic Ultrasound and measurements of glenohumeral internal rotation, external rotation, and posterior shoulder tightness were obtained. *Results:* The dominant arms had significantly less HR ($p < .001$), and GHIR ($p< .001$), but greater PCT ($p< .01$), and GHER ($p< .001$) than the non-dominant arm. Dominant IR was significantly different between the under 10-year-old group and the over 10-year-old group. There were no differences with regard to PST between shoulders or age groups. A significant, strong, negative correlation between dominant GHIR and GHER ($r = -.395$, $p < .05$), a significant, strong, negative correlation between HR and GHIR ($r = -.431$, $p \leq .01$), and a significant, strong, positive correlation between HR and GHER ($r = .448$, $p < .01$) were observed. Dominant PCT was strongly, positively correlated with GHER ($r = .322$, $p = .059$) was observed. *Conclusions:* The alterations in a youth baseball sample are similar to those observed in older baseball athletes. This is the first study to demonstrate greater PCT in the dominant arm of youth baseball athletes. The magnitude of HR differences in youth was shown to be similar to older baseball athletes. Alterations in glenohumeral ROM displayed similar trends of increased GHER, and decreased GHIR. The youth baseball population is developing adaptations consistent with older baseball athletes, indicating further research is needed to determine the developmental mechanisms in youth, and the potential injury risks associated with such adaptations in youth.

Chapter 1

INTRODUCTION

An increasing number of children in the United States are participating in overhead sports annually, and sport-specialization is occurring at a younger age (Leonard & Hutchinson, 2010). This rise in numbers corresponds with an observed increase in overuse pathologies to the upper extremity. It is theorized that these injuries are related to an increased emphasis of sports specialization at younger ages (Brenner & and the Council on Sports Medicine and Fitness, June 2007). The increased incidence of overuse injuries is concerning as they often re-occur and lead to even more serious pathologies throughout one's lifespan, such as rotator cuff pathology, or premature osteoarthritis (Maffulli, Longo, Gougoulias, Caine, & Denaro, 2011).

Chronic injuries to the shoulder are a more common occurrence in youth baseball (Leonard & Hutchinson, 2010). Pediatric athletes aged six to twelve are at an increased risk of developing overuse injuries, such as proximal humeral epiphysitis, which results from the repetitive stresses of throwing on immature musculoskeletal structures (Leonard & Hutchinson, 2010). It has been shown that adolescent throwing athletes are capable of subjecting their shoulders to harmful torques throughout the throwing motion (Fleisig, Andrews, Dillman, & Escamilla, 1995). Since the propensity for overuse injury is elevated in the young overhead athlete, health care providers must understand the functional and structural alterations that occur in unison with maturation and continued participation in an overhead sport.

The most common shoulder complaint observed in adult overhead sports is subacromial impingement syndrome (SAIS), accounting for 44-65% of all shoulder injuries at a physician's office (van der Windt et al., 1996). Illustrating the lack of knowledge pertaining to the origin and prevention of chronic shoulder injuries is the fact that large percentages of individuals seek medical attention (van der Windt, Koes, de Jong, & Bouter, 1995). During overhead throwing the shoulder is repeatedly exposed to noxious stresses and positions potentially leading to tissue damage. Biomechanically, during the late cocking phase of throwing, the humerus is externally rotated and abducted resulting in contact pressure between the supraspinatus and posterior superior aspect of the glenoid fossa and labrum (Leonard & Hutchinson, 2010). This position can lead to excessive microtrauma and wear on the structures that pass through the subacromial space and/or lead to the development of SAIS (Burkhart, Morgan, & Kibler, 2003). SAIS has been reported in the literature in an older population, but limited research is available for a pediatric population. Additional research is needed to establish when adaptations occur that may be potential risk factors, even in the pediatric athlete.

Chronic injuries typically present clinically with an insidious onset, especially in the youth athlete, but there are several potential predisposing factors at the glenohumeral joint, including both functional and structural adaptations. One such functional adaptation, posterior shoulder tightness (PST), is believed to be associated with muscular hypertrophy and thickening of the posterior glenohumeral joint capsule from stresses of repetitive throwing. Cadaveric research has shown that posterior-inferior capsule tightening causes an increase in both contact pressure and contact area under the subacromial arch during the pitching motion, potentially leading to a complaint of shoulder pain (Muraki et al., 2010a). Myers et al. found that throwing athletes previously diagnosed with internal impingement had significantly greater PST, illustrating its role as a factor of interest for research (2006). Further complicating PST, is the osseous adaptations, such as humeral retroversion, that can change alignment of the humerus and glenoid. This could, theoretically, result in greater forces being applied to the remaining tissue around the shoulder. These forces may lead to stress induced hypertrophy (thickening) of all tissues and potentially cause overuse injuries. Additional research on the interaction between PST, posterior capsule thickness (PCT), and osseous adaptations is needed.

Throughout physical maturation the osseous tissue of the humeral head rotates from a position of external rotation (retroversion) to a more internally rotated (anteverted) position. Anthropological data on humeri of children found that by eight years of age, retroversion was consistent with the higher ranges observed in adults (Edelson, 2000). An investigation by Yamamoto et al. found that humeral retroversion (HR) angle decreased with age in an elementary and junior high sample but that the decrease was smaller on the dominant side. These results suggest that arm dominance may play an important factor in the development of degree of retroversion (2006).

Yamamoto et al. postulate that the effects of repetitive throwing motion do not increase HR but rather restrict normal physiological rotation during maturation (2006). Previous research has shown that the forces acting on the shoulder during the pitching motion are strong enough to cause damage to the epiphysis (Sabick, Kim, Torry, Keirns, & Hawkins, 2005; Yamamoto et al., 2006). Therefore if the forces during the pitching motion can affect the epiphysis, young throwers may be producing shoulder torques that cause adaptive changes to the cartilaginous epiphysis. Quantification of the side-to-side differences between humeri may be useful to future clinicians if it is related to heightened risk of shoulder pathology. Osseous adaptations are only one facet of the structural changes that have been observed in overhead athletes.

The structural changes associated with throwing have been well documented in youth athletes (Mair, Uhl, Robbe, & Brindle, 2004; Murachovsky et al., 2010). Researchers have hypothesized that increased HR accounts for a shift in the total arc of motion, allowing the glenohumeral joint increased external rotation while decreasing tension on the anterior inferior capsular ligamentous structures of the glenohumeral joint (Crockett et al., 2002; Leonard & Hutchinson, 2010; Sabick, Kim, Torry, Keirns, & Hawkins, 2005). Thomas et al. found supportive evidence in discovering that HR was negatively correlated with glenohumeral internal rotation, and positively correlated with glenohumeral external rotation (2011).

Clinicians have assumed that the osseous changes, such as HR, occur prior to the fusion of the epiphyseal growth plates (Borsa, Laudner, & Sauers, 2008; Crockett et al., 2002; Osbahr, Cannon, & Speer, 2002). However, the evidence is limited, because the relationships between HR and glenohumeral IR/ER have not been substantiated in a pre-adolescent cohort. Moreover, the shift in the total arc produces a decrease in shoulder internal rotation, creating a shorter arc through which the arm can decelerate during the follow-through phase (Osbahr, Cannon, & Speer, 2002). The smaller arc may be detrimental to the soft tissue and muscular structures that eccentrically decelerate the arm, including the posterior rotator cuff musculature and posterior capsule. If the musculature of youth athletes in particular, cannot adequately absorb these forces, then the posterior joint capsule may adapt a larger role in maintaining joint stability over time.

The posterior capsule is vital to stability of the glenohumeral joint throughout the deceleration phase of the throwing motion. Burkhart et al. proposed that posterior capsule hypertrophy is the seminal soft-tissue adaptation in overhead throwers (2003). The tremendous forces produced to propel the ball during the acceleration phase, which is enhanced by greater external rotation associated with HR, could be amplifying the adaptive thickening of the posterior capsule (Thomas et al., 2012).

Studies investigating collegiate baseball players have discovered that HR and posterior capsule thickness are significantly positively correlated (Thomas et al., 2011; Thomas et al., 2012). Indicating that HR and PCT are related in collegiate baseball athletes, but the extent of that relationship in an adolescent throwing sample is unknown. Furthermore, HR and PCT have been shown to be significantly greater in the dominant than the non-dominant shoulder in collegiate baseball players (Thomas et al., 2011; Thomas et al., 2012). Whether this observation holds true in adolescent athletes remains to be determined. Yamamoto et al. found HR to be greater in the dominant compared to non-dominant shoulder in elementary and middle school aged overhead athletes (2006). It is generally assumed that PST and PCT are positively correlated, but this assumption is unsubstantiated. It also remains to be discovered whether HR and PCT are greater in a young throwing population, and how HR relates to PST, and subacromial space, as well as glenohumeral internal and external rotation. Knowledge pertaining to the skeletally immature throwing athletes will be instrumental to understanding the short and long-term effects these adaptations have throughout life. It was the goal of this study to further the understanding concerning all three anatomical adaptations and three functional shoulder measures in a youth aged baseball cohort.

***Specific Aim 1*: To determine effect of age and throwing on joint range of motion and structural changes.**

***Hypothesis 1.1:* There will be a significant interaction effect between dominant and non-dominant shoulder for both glenohumeral external and internal rotation.** Yamamoto et al. found significant differences when comparing dominant to non-dominant glenohumeral ER and IR in a sample of young throwers from elementary school through middle school ages (Yamamoto et al., 2006). Meister et al. found that elevation, internal rotation at 90°, external rotation at 90°, and total range of motion varied significantly among age groups (2005). It is expected the results will be in agreement with previous studies that used similar samples.

Hypothesis 1.2: **Differences in humeral retroversion, posterior capsule thickness, and glenohumeral external rotation compared between dominant and non-dominant shoulders will have a significant interaction effect of age group.** The biceps-forearm angle was significantly higher on the dominant compared to non-dominant shoulder, when isolating for group alone, only fifth graders had a significant difference between arms (Yamamoto et al., 2006). Yamamoto et al. found significant differences in glenohumeral ER between dominant and non-dominant but were unable to show significant differences between age groups (2006). No studies were found investigating PCT in an adolescent age group. Meister et al. found significant differences between the 8 year old group and 16 year old group when comparing external rotation at 90°. It is expected that the results of the proposed study would be in agreement (Meister et al., 2005).

Specific Aim 2: **To investigate the relationship between measures of anatomical adaptations and passive shoulder range of motion among youth athletes.**

Hypothesis 2.1: **Humeral retroversion and glenohumeral posterior capsule thickness will be greater in the dominant than the non-dominant shoulder in both age groups.** Yamamoto et al found that the humeral retroversion angle decreased with respect to age but that the decrease was attenuated in the dominant shoulder (Yamamoto et al., 2006). Thomas et al. found that HR and PCT were greater in the dominant shoulder than the non-dominant in collegiate aged athletes (Thomas et al., 2011; Thomas et al., 2012). It is to be expected that the results of the proposed study will have a similar trend.

Hypothesis 2.2: **Subacromial space will not be significantly different between dominant and non-dominant shoulders.** Research has shown that in overhead throwers the dominant side subacromial space is significantly smaller than the non-dominant side (Maenhout, Van Eessel, Van Dyck, Vanraes, & Cools, 2012). However, the population included in the study had diagnosed glenohumeral internal rotation deficit, and might not hold true in an un-injured sample. We expect there to not be a statistically significantly different between dominant and non-dominant shoulders in young healthy overhead athletes.

Hypothesis 2.3**: Posterior shoulder tightness will correlate with posterior capsule thickness, and be correlated with a decrease in passive internal glenohumeral rotation.** Thomas et al. found that PCT has a significant negative correlation with glenohumeral IR. Although PCT does not directly indicate posterior shoulder tightness, this study will attempt to determine if a relationship exists between posterior shoulder tightness and PCT in a young throwing cohort. No studies to date were found that investigated the relationship between posterior shoulder tightness measures and PCT.

To accomplish the specific aims, a post-test only experimental design, of male youth baseball athletes aged eight to twelve years old was used. A factorial Analysis of Variance (ANOVA) with one within subjects factor (2 levels-dominant or non-dominant arm) and one between subjects factor (2 levels-age group) will be utilized.

The dependent variables will be humeral retroversion, posterior capsule thickness, subacromial space, internal glenohumeral rotation, external glenohumeral rotation, and posterior shoulder tightness.

Chapter 2

METHODS

2.1 Experimental Design

The study utilized a one group post-test only experimental design. The independent variables were arm (dominant or non-dominant), and age group. The dependent variables included humeral retroversion (HR), posterior capsule thickness (PCT), width of subacromial space (SAS), glenohumeral internal rotation (GHIR), glenohumeral external rotation (GHER), and posterior shoulder tightness (PST).

2.2 Participants

Thirty-five healthy male volunteer participants within the 8-12 years old age range were recruited from the local population of youth baseball athletes. The number of subjects was determined through an a priori power analysis utilizing G*Power v3.1.2 (Heinrich-Heine-Universitat Dusseldorf) with parameters set at α=0.05, 1-β=0.80. Subjects were grouped based on age into two groups, one group under 10-years-old, and one group over 10-years-old. Volunteers were recruited using word of mouth, flyers placed at local youth baseball fields, and visitations with coaches and parents of local youth baseball teams. The age groups were chosen because humeral retroversion measurements have been shown consistent with the high range of adult values by eight years of age (Edelson, 2000).

Exclusion criteria included: (1) any current or recent (past 6 months) boney, muscular, or joint injuries to the elbow, or shoulder (2) any history of fracture to either humerus, ulna, radius, clavicle, or scapula, (3) any previous surgeries to either elbow or shoulder as reported on health history questionnaire.

2.3 Instrumentation

2.3.1 Diagnostic Ultrasound:

A commercially available compact ultrasound system (Sonosite Titan, Sonosite Inc., Bothell WA) and 13 MHz linear transducer was used to collect and measure the degree of humeral retroversion, posterior glenohumeral capsule thickness, and the width of the subacromial space. Intraclass Correlation Coefficients (ICC) were calculated to assess reliability of the primary investigator for all measurements and all ICC's were above 0.92.

2.3.2 Inclinometer:

Humeral retroversion and glenohumeral internal and external rotation was measured using TiltMeter application for IPhone4S (© IntegraSoftHN). Intraclass Correlation Coefficients (ICC) were calculated to assess reliability of the primary investigator for all measurements and all ICC's were above 0.92.

2.4 Procedures

All testing was completed in the University of Delaware's Human Performance Laboratory (HPL), or at local baseball fields, or training facilities. Subjects were asked to report for a 30 minute testing session. Upon arrival subjects and parents or legal guardians read and sign informed consent and a health history questionnaire (Appendix A). A copy of the assent form was given to each subject and read over with the investigator. Parents or guardians were required to throughout the duration of testing. Six dependent variables were measured for the dominant, and non-dominant arm: humeral retroversion, posterior capsule thickness, and width of subacromial space, glenohumeral internal rotation, glenohumeral external rotation, and posterior shoulder tightness. Each measure was performed twice to ensure a reliable measurement, and averaged for data analysis.

2.4.1 Humeral Retroversion

Humeral retroversion was measured with subjects lying supine on a treatment table. The subject's arm abducted to 90° and the elbow flexed to 90° with palm facing towards the subject. Standard acoustic coupling gel was applied. The ultrasound transducer was placed on the anterior aspect of the subjects' shoulders. The transducer was maintained in a vertical position while the subject's arm was moved into internal or external rotation until the bicipital groove was oriented vertically on the ultrasound monitor. The transducer was verified to be vertical with the use of an inclinometer.

Once the bicipital groove was pointed vertically on the ultrasound monitor, a digital inclinometer was placed just proximal to the ulnar styloid process and along the shaft of the ulna as described by Thomas et al 2011. The degree of rotation was recorded.

2.4.2 Posterior Capsule Thickness

For measurement of the posterior capsule thickness, subjects were seated upright with their arms resting at their side and forearm resting on their thighs. Standard acoustic coupling gel was applied, and the ultrasound transducer placed on the posterior aspect of the shoulder to visualize the humeral head, glenoid labrum, and rotator cuff musculature. The posterior capsule was identified as the tissue immediately lateral to the edge of the labrum between the humeral head and rotator cuff musculature. Once the capsule was identified, via the image on the screen of the ultrasound machine, the image was paused and the thickness of the posterior capsule measured using the caliper software that comes standard on the Sonosite Titan. The calipers were manually placed by the primary investigator on the edges of the posterior capsule, directly next to the edge of the glenoid labrum as described by Thomas et al 2011. The image was then saved to a portable hard drive and removed after testing was completed. The measurement was recorded on the data collection sheet.

2.4.3 Subacromial Space

The subacromial space was measured with the subjects seated upright with their arms at their side and forearms resting on their thighs. Standard acoustic coupling gel was applied; and the ultrasound transducer placed on the midpoint of the lateral edge of the acromion. The acromion, humeral head, and rotator cuff musculature were identified in the ultrasound monitor. The width of the subacromial space was recorded as a perpendicular line from the lateral most edge of the acromion to the humeral head. Once identified, via the image on the screen of the ultrasound machine, the image was paused and the width of the subacromial space measured using the caliper software that comes standard on the Sonosite Titan. The calipers were manually placed by the primary investigator on the lateral most edge of the acromion, and directly inferior to the humeral head as described by Thomas et al 2011. The image was saved to a portable hard drive and removed after testing was completed. The measurement was recorded on the data collection sheet.

2.4.4 Passive Glenohumeral Internal and External Rotation

Passive glenohumeral internal and external rotation measurements were performed with the subject lying supine on treatment table. The shoulder abducted to 90° and elbow flexed to 90° with palm facing the subject. The examiners hand stabilized the scapula and the arm was rotated in either internal or external rotation until scapular motion was felt. Once scapular motion was detected rotation stopped and an inclinometer was placed on shaft of the ulna with the distal edge of the inclinometer at the base of the styloid process of the ulna. Once positioned the measurement was recorded off the inclinometer.

2.4.5 Posterior Shoulder Tightness

Posterior shoulder tightness was examined using the method described by Myers et al. 2006, with the subject lying on the non-tested side, with both hips and knees flexed to 90° of flexion. The non-tested arm was flexed to 180° shoulder flexion and positioned under the subjects' head. The medial epicondyle was marked with a felt tipped pen. The acromion was aligned perpendicular to the table and spine maintained in a neutral position. Scapular motion was restricted by stabilizing the lateral border of scapula in the retracted position by the investigator, the humerus was abducted to 90° with 0° of humeral rotation for the beginning of the test. With the subject relaxed the investigator passively lower the arm into horizontal adduction without rotation and maintaining scapular stabilization. Maximal horizontal adduction or initiation of scapular motion was considered end range of motion. At end range of motion, a tape measure was used to measure the distance, in centimeters, between the mark on medial epicondyle and the table surface. All measurements were taken bilaterally.

2.5 Data/Statistical Analysis

Data were analyzed using SPSS statistical software. A two-way analysis of variance (ANOVA, $p<0.05$) was utilized to determine if there was a difference within subjects, as well as between age groups for humeral retroversion, posterior capsule thickness, subacromial space, glenohumeral internal and external rotation, and posterior shoulder tightness. A post hoc analysis was also be used when appropriate.

Pearson-product correlation coefficients were calculated between all dependent variables prior to statistical analysis to determine potential covariates. An alpha level of .05 was set *a priori* to represent statistical significance.

Chapter 3

RESULTS

A total of 36 subjects ($\bar{x}_{age}$=10.94 ± 1.34 yrs, $\bar{x}_{Ht}$=151.31 ± 12.17 cm, and $\bar{x}_{mass}$=42.51 ± 10.32 kg) participated in this investigation. One subject was removed at the discretion of the primary investigator because of non-compliance with the testing protocol. Subject demographic data are presented in Table 1. Due to the lack of a complete data set for subacromial space, it was excluded from statistical analysis.

3.1 Dominant and Non-dominant Arm Comparison

Results for comparison between arms is presented in Table 2. There were significant main effects ($p<.05$) for arm dominance in HR, IR, ER, and PCT. Specifically, subjects' HR was significantly greater in the dominant arm ($\bar{x}$= -11.18° ± 13.39°) than the non-dominant arm ($\bar{x}$= -24.04° ± 10.58°)(Figure 1). Glenohumeral ER ($\bar{x}$=152.47° ± 14.08°) (Figure 2) and PCT ($\bar{x}$=1.294 ± 0.239 mm) (Figure 3) were also significantly greater in the dominant arm than the non-dominant arm (GHER $\bar{x}$=131.50° ±12.14°; PCT $\bar{x}$=1.183 ± 0.185 mm). Conversely, GHIR was significantly less on the dominant arm ($\bar{x}$=61.93° ± 12.01°) than non-dominant arm ($\bar{x}$=75.10° ± 8.50°)(Figure 4). There was no significant difference (p= .184) in PST when comparing dominant arm ($\bar{x}$=7.03 ± 2.07 cm) and non-dominant arm ($\bar{x}$=6.40 ± 3.04 cm) (Figure 5).

3.2 Age Comparisons

The 2X2 ANOVA showed a significant interaction effect between age group (group 1=under 10 years old, group 2=over 10 years old) and arm dominance ($p=.05$) for GHIR. Post hoc analysis showed that the older athletes exhibited significantly less GHIR compared to young group ($\bar{x}=60.2° \pm 12.79°$, $\bar{x}=64.2° \pm 10.88°$) respectively on the dominant side (Figure 6). No difference was observed between groups for the non-dominant side. No significant interaction effects were observed for GHER, PST, HR, or PCT. The results of the ANOVA are presented in Table 2.

3.3 Correlation between Measures

Posterior shoulder tightness showed no correlation between any other dependent variables for either dominant or non-dominant arm. However, glenohumeral internal rotation exhibited a significant, negative correlation with GHER ($r= -0.395$, $p= .019$) and HR ($r= -0.431$, $p= .010$) on the dominant side (Figure 7). GHER was significantly correlated with HR ($r= 0.448$, $p= .007$) on the dominant side (Figure 8). GHER was moderately correlated with PCT ($r= 0.322$, $p= .059$) on the dominant side, but did not achieve statistical significance. GHIR exhibited significant, negative correlation with HR ($r= -0.334$, $p= .05$) for the non-dominant side. Years played was shown to be significantly correlated with PCT ($r= 0.352$, $p= .038$) for the non-dominant side.

Table 1: Subject Demographics

Subject Demographics	
	Mean ± SD
Age	10.94 ± 1.35 years
Height	151.31 ± 12.17 cm
Mass	42.51 ± 10.33 kg
Years Played	6.00 ± 1.77 years

Table 2: Results

Table 2: (*) indicates statistical significance

Results				
		Mean ± SD	Significance (p value)	F Statistic
HR				
	Dom	-11.18 ± 13.39°	< .001*	25.51
	Non-Dom	-24.04 ± 10.58°		
GHIR				
	Dom	61.93 ± 12.01°	< .001*	54.83
	Non-Dom	75.10 ± 8.50°		
GHER				
	Dom	152.47 ± 14.08°	< .001*	116.64
	Non-Dom	131.50 ± 12.14°		
PST				
	Dom	7.03 ± 2.07 cm	.184	1.84
	Non-Dom	6.40 ± 3.04 cm		
PCT				
	Dom	1.294 ± 0.238 mm	.004*	9.87
	Non-Dom	1.183 ± 0.185 mm		

Figure 1: Humeral Retroversion

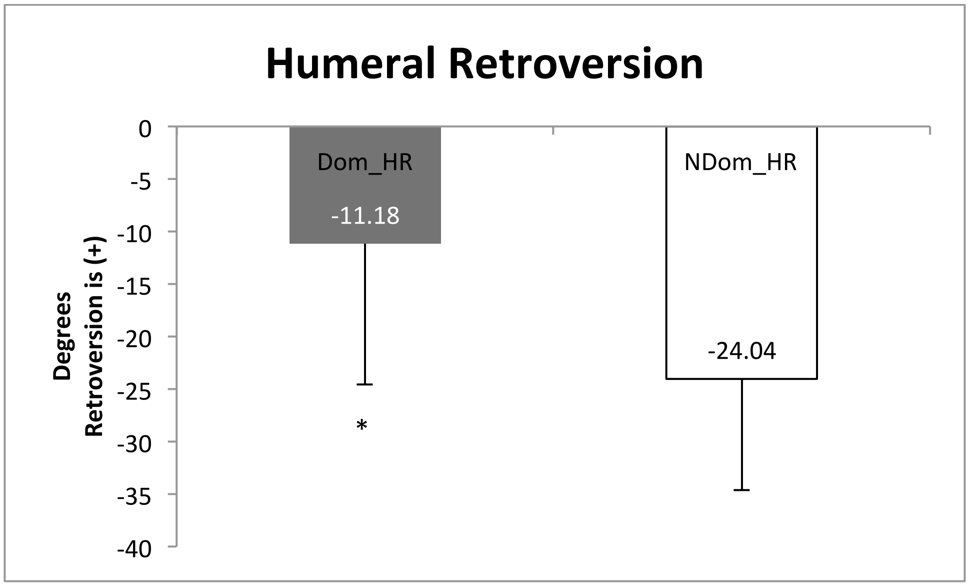

Figure 1: Humeral Retroversion. Dominant HR is significantly ($p < .001$) greater than non-dominant HR.

Figure 2: Glenohumeral External Rotation

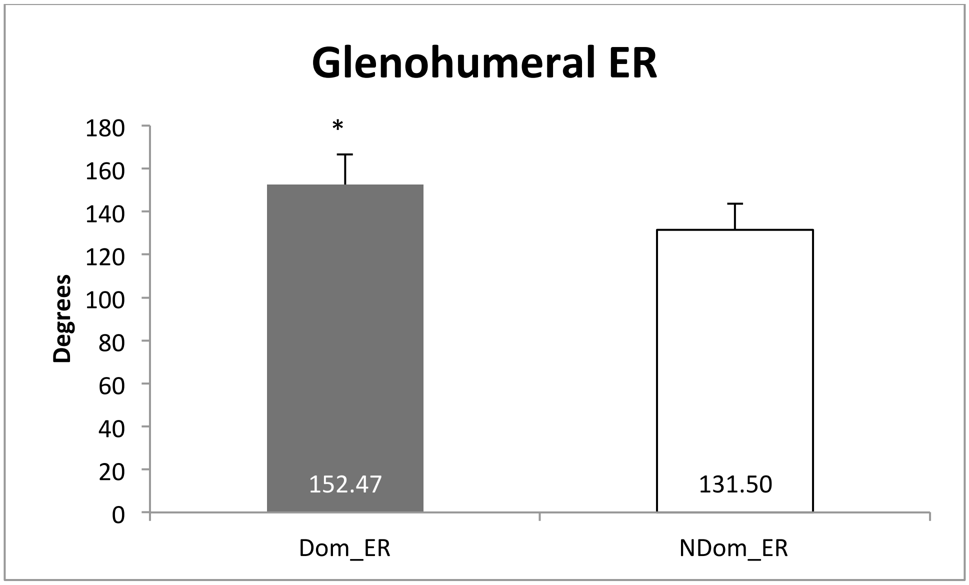

Figure 2: Glenohumeral ER. Dominant glenohumeral ER was significantly ($p < .001$) greater than non-dominant glenohumeral ER.

Figure 3: Posterior Capsule Thickness

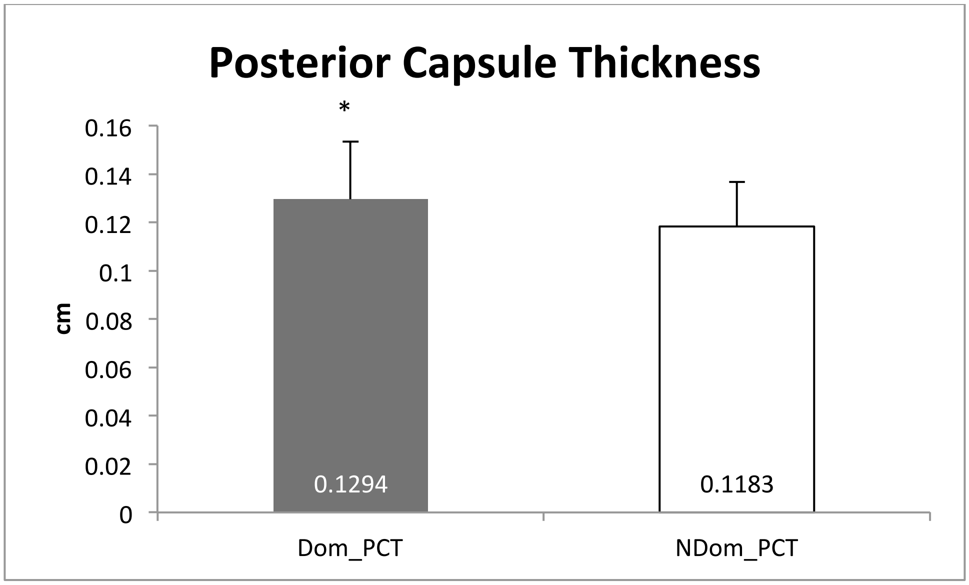

Figure 3: Posterior Capsule Thickness. Dominant PCT is significantly (p= .004) greater than non-dominant PCT.

Figure 4: Glenohumeral IR

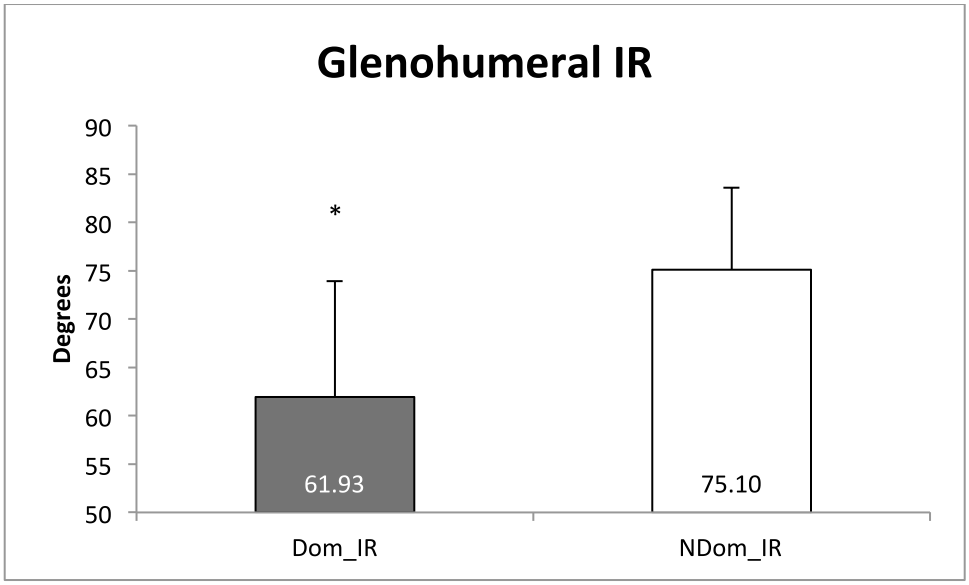

Figure 4: Glenohumeral IR. Dominant glenohumeral IR was significantly ($p < .001$) less than non-dominant glenohumeral IR.

Figure 5: Posterior Shoulder Tightness

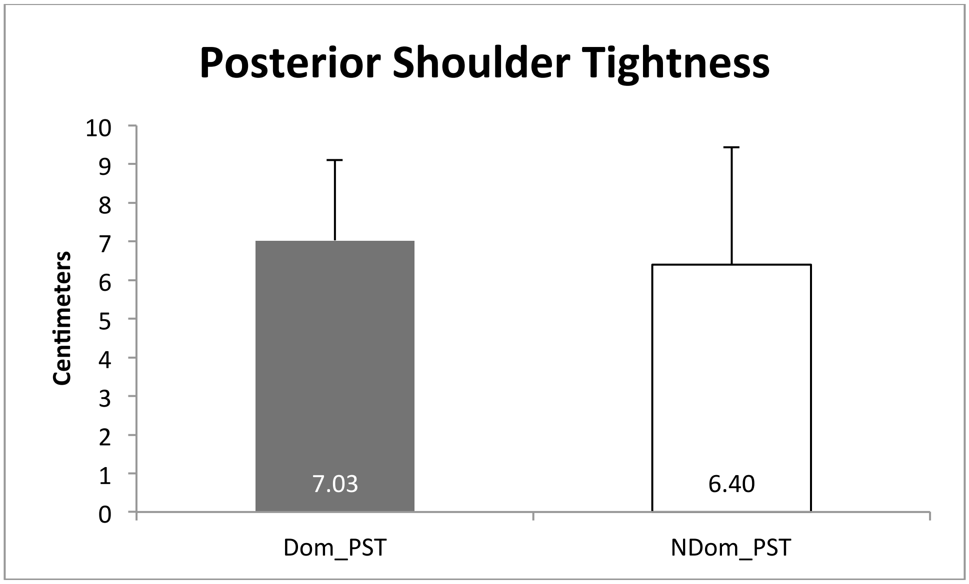

Figure 5: Posterior Shoulder Tightness: No significant difference between dominant and non-dominant posterior shoulder tightness measure.

Figure 6: Glenohumeral IR by Age Group

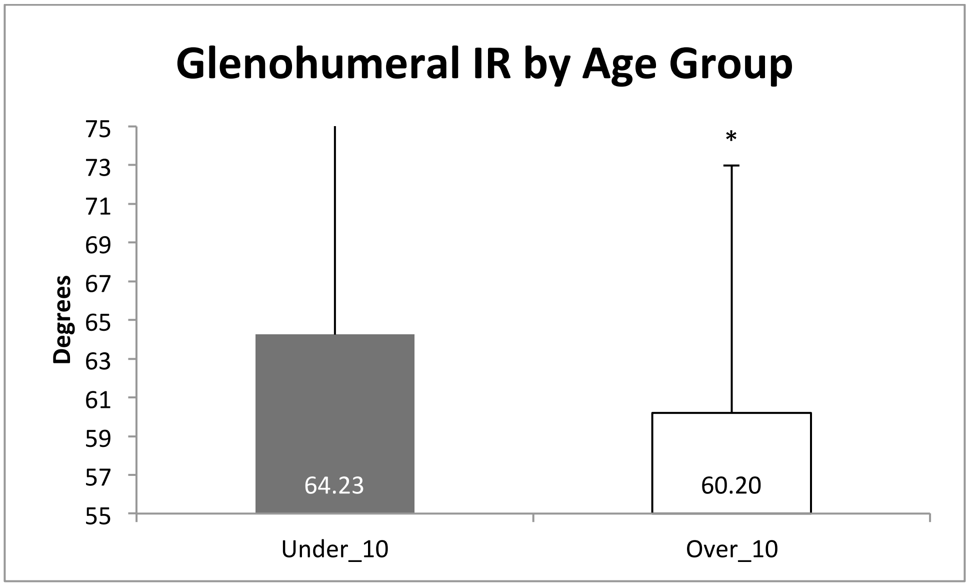

Figure 6: Dominant arm glenohumeral IR comparison by Age Group. Dominant glenohumeral IR was significantly greater in the under 10-year-old group compared to the over 10-year-old group.

Figure 7: Dominant HR and GHIR

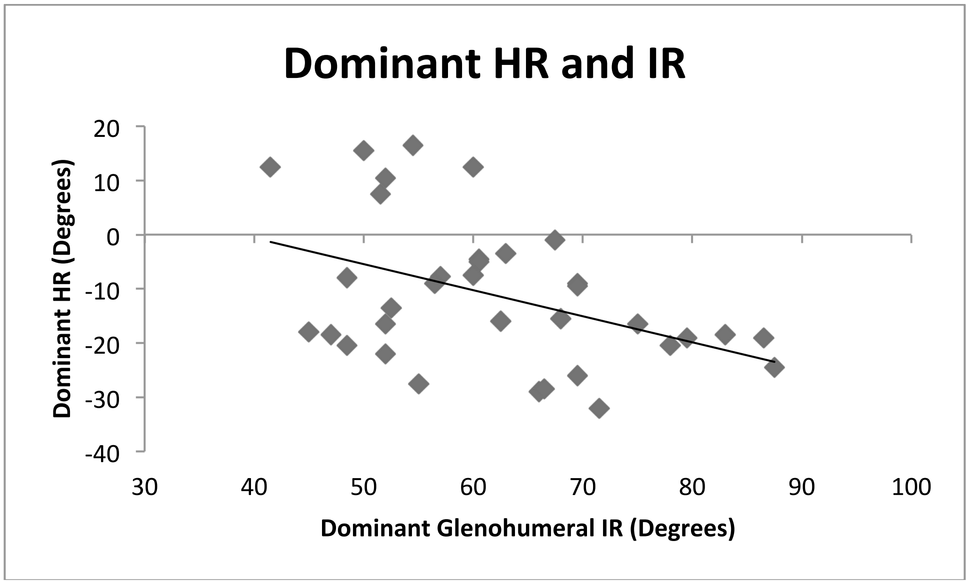

Figure 7: Dominant HR and GHIR. Dominant HR had a significant (p= .01) negative correlation with glenohumeral IR (r= -0.431).

Figure 8: Dominant HR and GHER

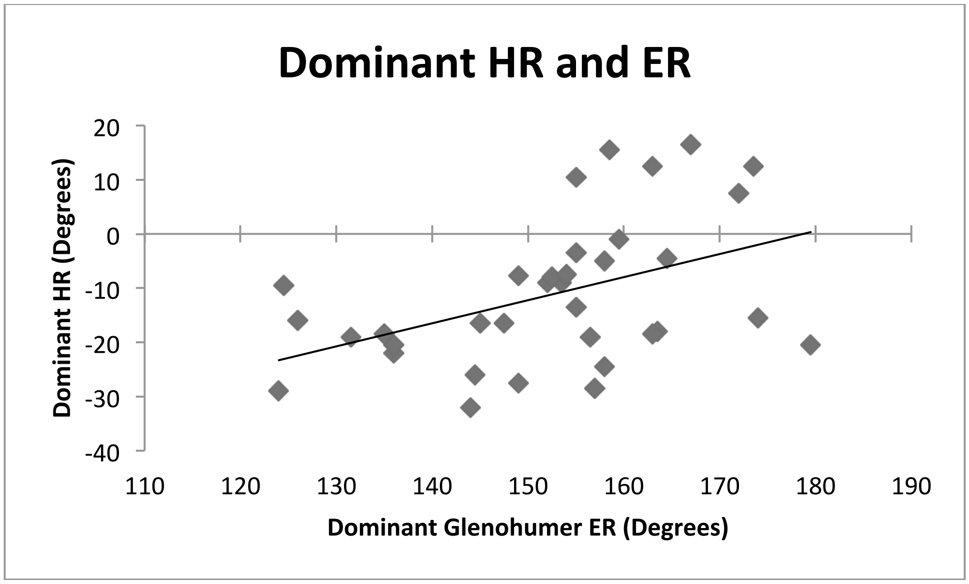

Figure 8: Dominant HR and GHER. Dominant HR had a significant (p= .007) positive correlation with glenohumeral ER (r= 0.448)

Chapter 4

DISCUSSION

The aim of the current study was to investigate the adaptations of the glenohumeral joint in a youth throwing population. Our results demonstrate differences in HR, GHIR, GHER, and PCT are observed between dominant and non-dominant arms. We did not observe differences in PST between shoulders. Our findings suggest that the glenohumeral joint adaptations observed in youth, high school, collegiate, and professional baseball athletes develop at a young age. Our results show that the youth throwing population warrants further attention to injury and pathology development, as well as prevention and rehabilitation strategies for youths at risk, and supports the use of ultrasound as a clinical diagnostic screening tool.

A significant difference in HR was found between dominant arm and non-dominant arm. These results agree with previously reported literature that shows greater HR on the dominant side(Roach, Lieberman, Gill, Palmer, & Gill, 2012; Thomas et al., 2012; Whiteley, Ginn, Nicholson, & Adams, 2006; Yamamoto et al., 2006). Our results, of approximately a 13-degree difference, are greater than previous data identifying 3-degree variation in a group of elite elementary and middle school aged baseball athletes (Yamamoto et al., 2006). The divergence between Yamamoto et al. (2006) and our results may be attributable to the populations tested. Our subjects had more baseball experience and started pitching earlier than the subjects in the study by Yamamoto et al. (2006). It has been theorized that the opposing forces, of a distal ER torque and proximal IR torque, on the humerus during the late cocking phase of the throwing may be strong enough to lead to micro-damage of the epiphysis and slow down the normal maturational de-rotation process, ergo leading to greater HR (Edelson, 2000; Yamamoto et al., 2006). Therefore, the sum of the stresses of repeated throwing for 2.7 years longer in our sample may account for the difference in HR observed between the two studies(Yamamoto et al., 2006). Even though our results were different than another study on youth athletes, the variance in HR between shoulders was similar to other studies on older throwers that ranged between 10 and 17 degrees (Crockett et al., 2002; Osbahr, Cannon, & Speer, 2002; Oyama, Hibberd, & Myers, ; Thomas et al., 2012). This suggests that the differences observed in older athletes may potentially be achieved at a much younger age than previously assumed. The authors postulate that HR is one of the first structural adaptations to develop from throwing at a young age and may precipitate other changes in the surrounding tissue.

In addition to significant differences in dominant and non-dominant arms, HR displayed a significant negative correlation with GHIR, and a significant positive correlated with GHER. The strength of our correlations is similar to those reported in a previous study with collegiate baseball athletes (Thomas et al., 2012). The strength of the correlations reiterates the importance of HR to the magnitude of alterations in glenohumeral ROM in an overhead athlete. This is vital for researchers and clinicians to identify because the alterations in glenohumeral ROM may be mostly related to osseous adaptations not soft-tissue. Therefore, the effects of prevention and rehabilitation programs will be limited to soft tissue accommodations.

The strong relationship between HR and glenohumeral ROM is evident in the differences observed in GHIR and GHER when comparing the dominant arm to non-dominant arm. Our study found alterations in glenohumeral ROM consistent with the pattern of decreased GHIR and increased GHER when comparing the dominant arm and non-dominant arm. This has been previously documented in overhead athletes(Crockett et al., 2002; Hurd et al., 2011; Mair, Uhl, Robbe, & Brindle, 2004; McConnell & McIntosh, 2009; Meister et al., 2005; Thomas et al., 2011). Our observed average difference of 13-degrees less GHIR and 21-degrees greater GHER on the dominant arm is larger than most reported in the literature. However, the greater observed differences could also be attributable to higher total ROM in a youth population, and represent a selection bias. When investigating a similar age group, Meister et al. (2005) found that in a group of 11 year olds, the average difference in GHIR was 3 degrees, and GHER was 4 degrees. The differences between our results and those of Meister et al. may be attributable to the pooling of data of 8 to 12 year old athletes in our study, which could have introduced a greater variance due to the age and physical maturity range in our group compared to a homogenous group of 11 year olds. Nevertheless, the general trend is a GHIR loss, and GHER gain for the dominant arm compared to the non-dominant. This was shown to be evident in all age groups for both our study and Meister et al. (2005). The similar trend in both studies supports the theory that range of motion changes can occur at early ages. The shift in motion associated with overhead sports of increased GHER, and decreased GHIR may be detrimental, as it is believed to result in a decreased amount of rotational motion available after ball release during the follow-through phase. This decreased arc would then place additional stress on the posterior RC and posterior capsule, potentially increasing the risk of injury. It may also lead to stress induced hypertrophy of the posterior structures in an attempt to absorb and decelerate the arm. (Burkhart, Morgan, & Kibler, 2003).

Our analysis of GHIR revealed that baseball players under 10 years exhibited an average of 4 degrees more motion on the dominant arm when compared to athletes over the age of 10 years. This finding is in agreement with Meister et al. (2005) who showed a decrease in the GHIR of adolescent baseball players with an increase in chronological age. Meister et al. (2005) reported a decrease of 17.7-degrees in dominant arm internal rotation between 8-year-olds and 16-year-olds. This change is largely attributable to the increased HR on the dominant arm, but it may also be partially due to soft tissue contracture of the RC muscles or the glenohumeral joint capsule. Measuring contracture of the posterior musculature or the glenohumeral joint capsule is difficult as it is almost impossible to determine, without the use of imaging technology, which structure is responsible for the limitation in motion. Restrictions in horizontal adduction are a functional indication of contracture of the posterior structures of the shoulder(Tyler, Roy, Nicholas, & Gleim, 1999). This is most readily evaluated using a measure of PST as defined by Tyler et al (1999).

The current study is the first to investigate PST in youth athletes and its relationship with commonly used clinical measures, such as glenohumeral ROM, and structural changes associated with throwing. We found that PST was greater on the dominant arm compared to the non-dominant arm, but it was not significantly different. Our observed difference in PST (0.6 cm) between arms is slightly less than that found in healthy adults (0.9 cm) and less than that found in an injured population (J. Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). PST has been found to be greater in a population with diagnosed internal impingement, and cadaveric studies show that a tightening of the posterior capsule of the glenohumeral joint leads to increased contact force under the acromion(Muraki et al., 2010b; J. Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). Therefore, differences observed bilaterally in PST may be an identifiable risk factor for development of impingement type injuries. Several reasons exist as to why a significant difference in dominant and non-dominant PST was not observed. First, the large amount of variance in our measurement may be attributed to the difference in muscular hypertrophy of the youths' posterior shoulder, the uninjured nature of our subjects, or the inability of our young subjects to relax during testing. An additional factor that might have affected the significance of our PST measure was our methodology as we utilized the side-lying method because of comfort reasons for our young subjects. Even though this method is both valid and reliable, it is not as reliable as the supine method, thus potentially explaining our variance (J. B. Myers et al., 2007). Even though our data is not statistically significant, it may still be clinically relevant because even a small contracture of the posterior capsule limits horizontal adduction of the shoulder, thereby potentially increasing the risk of development of internal impingement, (J. Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). However, it remains to be discovered whether increased PST on the dominant side is consistent for youth athletes diagnosed with internal impingement, or if a quantifiable difference can be classified as an increased injury risk factor for youth or adult throwers.

The posterior capsule has garnered much attention recently and is becoming a greater focus in research(Clabbers et al., 2007; Muraki et al., 2012; Thomas et al., 2011; Thomas et al., 2012) with the increased availability of diagnostic imaging techniques. Previous studies have shown greater PCT on the dominant arm compared to the non-dominant arm (Thomas et al., 2011). To our knowledge, our study is the first to investigate adaptations to the posterior capsule in youth athletes. We observed that the dominant arm displayed significantly greater PCT than the non-dominant arm. This finding is in agreement with previous literature on collegiate baseball athletes (Thomas et al., 2011). Thomas et al. (2011) found an average difference of 0.39 mm when comparing dominant to non-dominant PCT. Even though our results on PCT reached statistical significance, we recognize the clinical meaning will need further research to substantiate. Since no research has been conducted to determine the magnitude of a difference that has clinical relevance for PCT, we cannot state whether the small difference (0.111mm) between dominant and non-dominant PCT in our subjects is related to pathology. Since our observed difference is three times less than that of collegiate aged baseball athletes(Thomas et al., 2011), we can speculate that side differences in PCT may originate in youth athletes, but then progresses at an unknown rate over time until it is much more pronounced in physical mature overhead throwers. It remains unknown if and when PCT becomes a pathological. However, it is known that a contracted or shortened posterior capsule results in a posterior-superior shift in the positioning of the humeral head during simulated pitching positions. This can lead to increased subacromial contact pressure and heightened risk of injury (Clabbers et al., 2007; Huffman et al., 2006; Muraki et al., 2010b). Our subjects were healthy, but future research may reveal a threshold for PCT, which is related to shoulder pathology and pain in youth players.

The posterior capsule is not only important by itself, but additionally because of the relationships to glenohumeral ROM. Our correlation analysis revealed a positive correlation between PCT and GHER in our subjects. This relationship trended towards significance and can be qualified as moderate. Similarly, Thomas et al. (2012) found strong, significant, positive correlation between PCT and GHER, and a strong, significant, negative correlation between PCT and GHIR. The theoretical shift in motion associated with greater HR provides support for the relationship between PCT and glenohumeral range of motion. This increase in HR leads to a decreased amount of rotational motion available after ball release to decelerate the arm during the follow through phase of motion. This decreased arc would then place additional stress on the posterior RC and posterior capsule potentially leading to stress induced hypertrophy of the posterior structures (Burkhart, Morgan, & Kibler, 2003). The lack of a PCT-GHIR relationship in our study may show that the effects of repetitive throwing at a young age have not yet accumulated to produce a meaningful relationship between PCT and GHIR. Conceivably other structures, such as the proximal humeral epiphysis, could be partly absorbing the stress produced thereby limiting the development of PCT and therefore preventing a relationship between PCT and GHIR from being observed. Additionally the age and physical maturation of the subjects could limit the observable differences.

Additionally, our study revealed almost no relationship between PCT and HR in contrast to the results of Thomas et al. (2012) who showed a strong, significant correlation between PCT and HR. The lack of a relationship between PCT and HR in our study provides evidence that the relationship between PCT and HR may not fully develop until physical maturity.

Subacromial space was excluded from advanced statistical analysis because of an incomplete data set. Subacromial space is important because of the adequate room required for the structures that reside under the acromion to move during the throwing motion (Huffman et al., 2006). Youth are at increased risk of developing subacromial impingement, due to the lack of strength of the rotator cuff muscles and a greater proportion of type III collagen compared to adults, leading to a potential laxity of the capsular and ligamentous restraints (Walton et al., 2002). Our method of measuring SAS in the neutral position was shown to result in greater acromiohumeral distance at rest than when the shoulder is in a position of flexion or abduction, potentially limiting the applicability of findings using a non-functional position for measurement (Hebert, Moffet, Dufour, & Moisan, 2003). No previous studies have been found that investigate SAS in a healthy youth overhead population. Data for SAS was unobtainable on some subjects due to multiple factors. The main limitation was that the subjects' smaller boney architecture did not allow for full conformity of the entire linear US transducer onto the anterior aspect of the shoulders. It would be beneficial to use an alternate transducer that permits smooth coupling with the body curvature of a youth's shoulder. In our limited observational data, we observed that SAS was slightly greater on the non-dominant arm compared to the dominant arm. However, the extremely limited data hinders the application of our results. Previously in healthy adults there was no difference between dominant and non-dominant arms(Maenhout, Van Eessel, Van Dyck, Vanraes, & Cools, 2012). We believe that SAS remains an important variable for future research because limited space may lead to injury (Leonard & Hutchinson, 2010).

Overall, the results of this suggest that some of the shoulder adaptations normally associated with college and adult baseball players also manifest in younger athletes. This is the first study to detect PCT differences in youth throwers. This is concerning because only after an average of 6 years of play these young athletes are presenting with physical adaptations known to relate with shoulder pathologies in adults. Additionally, the results of this study provide support for the use of ultrasound to screen for risk factors and monitor the degree of adaptations to throwing in youth.

Future research on HR development in overhead athletes should focus on the youth level of competition, and follow the progression over time. Reearchers can begin to narrow the precise age ranges at which shoulder adaptations to throwing may occur. Future research pertaining to the development of HR should focus on youth athletes potentially even younger than the current study. Interventional studies that look at the effects of using a lighter ball or strength training at a younger age on HR and PCT development. Interventional studies that look at the effects of stretching programs on alterations in ROM at a young age are needed as well. Studies into the development of PCT should focus on adolescent and teenaged athletes because skeletal and physical maturation occur throughout those ages. Further studies are also needed to investigate the structural and functional adaptations over games, seasons, and years in both athletes and non-athletes in an attempt determine the effect of age and time on these measures.

The current study has a few limitations. First, the lack of the utilization of a standardized physical maturity scale, such as Tanner staging, may have affected our age group comparisons. Using a physical maturity scale would have been a better predictor of physical maturity compared to chronological age and would allowed us to make better comparisons of developmental morphology. Second, the lack of adequate sample sizes to compare all variables chronological age limited the power and generalizability of the results to the two larger age ranges of the subjects. The variables used could be potential covariates and this was not accounted for in the current study design. The diagnostic ultrasound unit that was utilized for the study did not have the highest resolution available and could be improved upon with future data collection. A lack of complete data set for SAS, limits the results. Additionally, a vast majority of subjects subjectively reported participating on multiple teams, in multiple leagues, thereby limiting the applicability of the results to youth athletes who have similar playing histories.

In conclusion, this study observed that youth baseball athletes exhibit similar adaptations to overhead throwing as older athletes. This is the first study to find a difference between arms for PCT in a youth cohort, with the dominant arm showing greater PCT than the non-dominant. Our cohort demonstrated significantly greater amounts of HR on the dominant arm, and altered glenohumeral range of motion, specifically decreased GHIR and increased GHER on the dominant arm. The dominant arm exhibited greater GHIR in the under 10-year-old group, when compared to the over 10-year-old group. Lastly, they exhibit posterior glenohumeral joint capsule thickness on their dominant arm when compared to their non-dominant arm. Most importantly, the type and magnitude of adaptations observed in youth baseball athletes are similar to both healthy and injured adult baseball populations.

Chapter 5

BACKGROUND/SIGNIFICANCE

5.1 Youth in Baseball

Over-head throwing sports are one of the most popular for children and adolescents, evident by the fact that in 2010 a combined total of almost three million children were on an organized little league baseball or softball team (Little League Around The World, n.d.). This number does not take into account the children who play these sports at recess, in physical education class, or at home. As with any physical activity there is an inherent risk for both major and minor injuries while playing baseball. The American Academy of Pediatrics estimates the overall incident rate of injury to be between 2% and 8% of participants per year for baseball (Committee on Sports Medicine and Fitness, 2001). Research on high school baseball injury statistics has shown that 1.26 injuries occur per 1,000 exposures, with the shoulder being the most commonly injured body part at 18% (Collins & Comstock, June 2008). In contrast to Collins and Comstock's work, a recent study revealed an injury rate of 1.72 injuries per 10,000 exposures for high school baseball (Krajnik, Fogarty, Yard, & Comstock, 2010). The discrepancy is noteworthy because both studies used the same definitions of athlete exposures, the same classification for an injury, and additionally used the same national database of high schools. The discrepancy could be due to the random allocation of schools during the time periods used for each investigation. Although data on injury statistics is in disagreement, the stresses placed on the shoulder during the throwing motion possess the capability of causing anatomical adaptations and/or injury.

The throwing motion places extreme demands on the shoulder (Fleisig, Andrews, Dillman, & Escamilla, 1995). In order to successfully complete the motion the shoulder must have sufficient range of motion and the ability to maintain stability (Borsa, Laudner, & Sauers, 2008). This holds true for the prevention of injuries to the shoulder as well. The positions of the shoulder are vital to functional success of the motion, which is to propel an object as fast and as accurately as possible. However, they also have the potential to lead to injury, as the tissues responsible for stability are constantly changing depending on the specific position during the throwing motion. The glenohumeral joint has a ball and socket osseous architecture with six degrees of freedom. Stability is provided through the successful interaction of dynamic and static stabilizers. The dynamic stabilizers are the muscles that surround the shoulder, specifically the rotator cuff musculature. They contract and relax in an orchestrated pattern to provide optimal positioning of the humeral head in the glenoid fossa (Huffman et al., 2006). The static stabilizers are the ligaments and joint capsule of the shoulder, as well as the glenoid labrum, which helps to deepen the socket of the shoulder. A defect in any of the static or dynamic stabilizers can result in injury of the shoulder girdle complex. The shoulder is at maximal risk of injury during two key points of the throwing motion, during the transition from late cocking to acceleration, and during the follow through phase.

The throwing motion is broken down into sequences. The most important are the late cocking phase, and the follow through phases. The late cocking phase places the glenohumeral joint in maximal external rotation, abduction, and horizontal abduction; whereas the follow through position places the glenohumeral joint in internal rotation, adduction and horizontal adduction. During the follow through phase the posterior rotator cuff musculature contracts eccentrically to decelerate the arm. The combination of the extreme positions and the forceful contractions necessary for throwing result in tremendous stresses being placed on the tissues that compose the glenohumeral joint, specifically the humerus and the joint capsule. Research on professional and collegiate level baseball athletes has discovered that anatomical adaptations to the humerus and posterior capsule are present (Crockett et al., 2002; Thomas et al., 2011; Thomas et al., 2012). The question remains of when these adaptations occur, and if they are related to an increased risk of injury.

5.2 Humeral Retroversion

Roach et al. define humeral torsion as “the angular difference between the orientation of the proximal humeral head and the axis of the elbow at the distal humerus” (2012). The humeral torsion angle is measured at the intersection of the transepicondylar line distally, and a line evenly bisecting the articular surface of the humeral head proximally. The measurement frequently used in the clinical literature is humeral retroversion and the angle is measured simply in the opposite direction (Roach, Lieberman, Gill, Palmer, & Gill, 2012).

Research on humeral retroversion in the professional baseball pitchers showed that humeral head retroversion was significantly higher in the dominant compared to the non-dominant shoulder, with a mean difference of 17 degrees (Crockett et al., 2002). The authors postulated that the lack of difference in humeral retroversion between the non-dominant shoulder in pitchers and non-dominant shoulder in non-throwing group indicates that higher observed HR in the dominant shoulder in pitchers could be developmental (Crockett et al., 2002). Thomas et al. found mean HR differences between dominant and non-dominant of 16 degrees, consistent with the literature, providing further evidence that this adaptation could be occurring during osseous development (2011). Research using another sample of collegiate baseball pitchers found a mean difference of 10.1 degrees from dominant to non-dominant (Osbahr, Cannon, & Speer, 2002). The difference between the two collegiate studies could be due to methodology as Thomas et al. used diagnostic ultrasound, and Osbahr et al. used radiography. The difference could also be attributable to subject selection as Thomas et al. used a combination of position players and pitchers and Osbahr et al. used strictly pitchers. Both used sample populations that were physically mature.

Although multiple studies on HR in skeletally mature athletes exist, research-investigating HR in younger populations is scarce. During normal development the humerus rotates from a position of external rotation (retroversion) to a more internally rotated position (anteverted). This is supported by the work of Edelson who used skeletal remains to investigate HR in pediatric and adolescent aged children. It was found that the greater portion of the process of rotation was completed on average by 8 years of age, and by age 11 all specimen had reached adult parameters (2000). Yamamoto et al. found that bicipital-forearm angle was greater on average of 3 degrees in the dominant arm in youth pitchers with an average age of 12 years of age (2006). They used a measure of HR defined as the bicipital-forearm angle, which is a measure between a line passing directly through the humeral head and bicipital groove, and a line parallel to the forearm. The combination of these findings supports the idea that HR observed in older athletes is indeed developmental because it has been observed in athletes prior to epiphysis maturation. Therefore, additional studies that investigate when the differences between dominant and non-dominant values become meaningful are warranted. Humeral retroversion is meaningful because of the effects it has on glenohumeral range of motion, including external and internal rotation, and posterior shoulder tightness.

Furthermore, research pertaining to glenohumeral rotational range of motion has shed more light on the relationship with HR. Thomas et al. found a significant positive correlation between HR and glenohumeral external rotation, and a significant negative correlation between HR and glenohumeral IR (2011). Supporting those functional measures, such as ROM, can be clinically relevant non-invasive tools that help reveal structural changes. Meister et al. found significant differences between dominant and non-dominant glenohumeral joints for internal rotation and external rotation in a population of 8 to 16 year old baseball athletes (2005). If the findings of Thomas et al. are interpreted in conjunction with Meister et al. it can again be deduced that HR will be present in youth athletes. Therefore, differences in range of motion based on arm dominance as noted by Meister et al. may be attributable to differing degrees of HR, providing further support for the idea that HR development occurs at a young age.

It has been postulated that HR development may occur from opposing muscular forces that are generated by the throwing motion and applied to the growing humerus repetitively and may be enough to cause deformation (Edelson, 2000; Yamamoto et al., 2006). During the transition period from cocking phase to ball acceleration, the glenohumeral joint is in maximal external rotation. During the beginning of the ball acceleration phase the subscapularis, and pectoralis major contract, creating an internal rotation torque about the proximal humerus. The hand, distal humerus and forearm lag behind the proximal humerus during this phase and place additional torque on proximal humerus. The grouping of these two forces has been shown to produce a high external rotation torque in fourteen youth pitchers, with an average age of 12.1 years of age (Sabick, Kim, Torry, Keirns, & Hawkins, 2005). Just prior to maximal ER (arm cocked position), the peak value for external rotation torque about the long axis of the humerus was 17.7 ± 3.5 N•m (Sabick, Kim, Torry, Keirns, & Hawkins, 2005). This force alone could be enough to deform the epiphysis and lead to the development of humeral retroversion. The shift in ROM typically associated with throwing usually presents as an increase in GHER and a loss of GHIR, and is believed to be related to osseous and soft tissue adaptations from overhead throwing.

A shift in motion that allows for a greater amount GHER also permits a longer phase of ball acceleration during the throwing motion, theoretically leading to an increase in ball speeds. It has been theorized that this is a beneficial adaptation (Fleisig, Andrews, Dillman, & Escamilla, 1995; Pieper, 1998). However, the increase in GHER corresponds with a loss of GHIR and therefore a shorter arc of motion for deceleration of the arm. This in turn may place additional stress upon the posterior musculature while contracting eccentrically to slow the arm, thereby increasing the likelihood of overload of the posterior capsule leading to micro-damage, and fibroblastic proliferation of the connective tissue. Burkhart et al. have suggested that the posterior capsule hypertrophy is the seminal soft tissue event, leading to deficits in GHIR (2003).

5.3 Posterior Glenohumeral Joint Capsule

In addition to the affect high forces produced by the throwing motion have on the humerus they have also been found to have an affect on soft tissue structures. The most researched structure is the posterior capsule. It is a portion of the glenohumeral capsule complex consisting of the posterior band of the inferior glenohumeral ligament complex just proximal to the edge of the glenoid labrum. One cadaveric study found the typical thickness of the glenohumeral joint capsule to be between 1.32

and 4.47 mm (Ciccone II et al., 2000). The posterior capsule has garnered much attention recently as it was postulated to be a major contributing factor to superior labrum from anterior to posterior (SLAP) lesions in throwing athletes when contracted and thickened (Burkhart, Morgan, & Kibler, 2003). Huffman et al. found that in a throwers model (stretched anterior capsule, and plication of the posterior-inferior capsule) a significant posterior-superior shift of the humeral head apex occurred in the glenoid (2006). Further cadaveric research found that a contracted posterior capsule results in an increase in contact pressure and area under the subacromial arch during the follow through phase (Meister et al., 2005). The combination of altered glenohumeral mechanics and additional compression could potentially cause injuries to the structures that reside inferiorly to the subacromial arch. Evidence supporting this theory was observed in throwers with pathological internal impingement syndrome, as they exhibited greater posterior shoulder tightness compared to throwers without impingement (J. Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). Myers et al. used a novel method of measuring posterior shoulder tightness but were unable to differentiate between the posterior structures, rotator cuff or capsule as to which was responsible for the observed tightness. Research on the relationship between posterior shoulder tightness and posterior capsule thickness is scarce. However, the relationship between posterior shoulder tightness and internal rotation deficit has led to theories that the posterior capsule is the seminal event for alterations in range of motion typically observed in the throwing shoulder (Burkhart, Morgan, & Kibler, 2003).

Thomas et al. found that a thicker posterior capsule was associated with less glenohumeral IR, and a significantly associated with greater ER, and scapula upward rotation at three different measures of shoulder abduction in adult overhead athletes (2011). The fact that posterior capsule thickness is correlated to glenohumeral ROM and scapular alterations makes it a vital structure to be further investigated. Posterior capsule thickness is also positively correlated to humeral retroversion as well in adults, but the developments of these adaptations remain unclear (Thomas et al., 2011). Research on the interaction between HR and PCT in youth athletes is scarce, and requires further investigations to expand the understanding the roles these structures may have with regard to pathomechanics of the shoulder complex. Many questions regarding the development of PCT remain unanswered. The effects that PCT has on shoulder motion make it an important factor to consider when treating common overuse injuries.

5.4 Subacromial Space/Impingement

The subacromial space has been researched extensively, due to the large number of individuals who sustain impingement injuries in the athletic population. The subacromial space is defined by the humeral head inferiorly, the distal third of the acromion, and coracoacromial ligament superiorly. Tissues that reside in the subacromial space include the supraspinatus tendon, subacromial bursa, long head of the biceps tendon, and the glenohumeral capsule (L. Michener, McClure, & Karduna, 2003). Impingement accounts for the greatest percentage of shoulder disorders in a physician's office (van der Windt, Koes, de Jong, & Bouter, 1995). Two types of impingement exist: primary and secondary. Primary impingement results from extra-articular rotator cuff pathology, and is rare in adolescents. Secondary impingement is a condition in which the humeral head is unable to stay properly located within the glenoid fossa during motion (Zaremski & Krabak, 2012). Both types of impingement can be directly associated with the amount of space available through which the subacromial structures pass.

Secondary impingement syndrome is an important issue in the young throwing population because of the general weakness associated with the rotator cuff musculature, which does not allow proper humeral head positioning throughout the throwing motion. Youth have been found to have greater type III collagen compared to adults potentially leading to laxity of the capsular and ligamentous restraints of the shoulder. This laxity allows more migration of the humeral head within the glenoid fossa during throwing (Walton et al., 2002). Lastly, the altered contact area and pressure shown to occur with a tightened posterior capsule may predispose young throwing athletes to develop secondary impingement syndrome, through a mechanical pinching mechanism (Muraki et al., 2010a). The dynamic stabilizers of the adolescent shoulder are also weaker and therefore allow more motion of the humeral head(Walton et al., 2002). This in combination with the altered posterior-superior shift of the humeral apex contact point, and increased laxity in the static stabilizers may cause a physical decrease in the width of the subacromial space placing them at an increased risk of injury(Grossman et al., 2005; Muraki et al., 2010a). However, knowledge about the relationship between subacromial space and posterior capsule thickness is limited. A clear understanding of this relationship could allow for evidence-based decisions on medical care to determine which structures are more or less responsible for the impingement in a youth population. Subacromial impingement syndrome is complicated, and it is beyond the scope of this study to investigate all the factors postulated to be involved. This study will attempt to look at one factor: the amount of space that is available on both the dominant and non-dominant shoulder of a young throwing cohort.

5.5 Diagnostic Ultrasound

Diagnostic ultrasound is currently becoming a popular clinical diagnostic tool and has been shown to be reliable for visualization of humeral retroversion, the posterior capsule thickness, and subacromial space (Seitz & Michener, 2011; Thomas et al., 2011; Thomas et al., 2012; Whiteley, Ginn, Nicholson, & Adams, 2006). This study continues the work already completed in the Human Performance Lab at the University of Delaware by using diagnostic ultrasound as the main method to investigate structures in-vivo. A recent investigation found that ultrasonographic assessment of HR was comparable in accuracy with computed tomography(J. B. Myers, Oyama, & Clarke, 2012). They found that ultrasound had reliability coefficients ranging from .991 to .997 with approximately 1° of measurement error compared to reliability coefficients for CT which ranged from .805 to .933 with approximately 3.5° of measurement error (J. B. Myers, Oyama, & Clarke, 2012). Myers et al. validate the use US as a clinical tool for investigating HR in a throwing population; the study population they used though was collegiate baseball athletes and not children. Furthermore diagnostic ultrasound does not expose subjects to ionizing radiation such as x-ray and computed tomography (CT) scan, and is more cost effective than x-rays and CT scans, as the imagining equipment is less expensive, and easy to use (Saini et al., 2000; Thomas et al., 2011; Thomas et al., 2012). This tool may allow for clinicians in the near future to perform pre-participation screenings and determine if athletes are at risk, or if interventions are warranted. Compared to MRI, and CT scan, diagnostic ultrasound is cost effective. A study found that the technical costs per examination were $50.28 for ultrasound, $112.32 for CT scan, and $266.96 for MRI (Saini et al., 2000). With medical spending being carefully scrutinized, more cost effective methods will become more prevalent. The user-friendliness and portability of diagnostic ultrasound allow for it to possibility be a convenient tool for future clinicians in helping to identify structural abnormalities and prevent injuries.

5.6 Significance/Innovation

This study is innovative because it will investigate three of the main structures that have been hypothesized to be associated with common shoulder disorders in youth. To our knowledge, this study is the first to use this methodology on a young throwing cohort in an attempt to unearth knowledge about anatomical structures that have clinical significance. Additionally functional measures, glenohumeral IR/ER and posterior shoulder tightness will be investigated and compared to the anatomical findings. Lastly, choosing a sample between 8 years and 12 years of age could potentially narrow the age range for when the development of these shoulder adaptations occurs.

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Appendix A

HEALTH HISTORY QUESTIONNAIRE

ID #:________________________________ Date:______________
____

Age:________ Height:____________ Weight:_________________

---

1. Which hand does your child throw with?
Right_______ Left________

2. How many years has your child played baseball?_____________

3. How many months out of the year does your child participate in organized baseball?
____

4. What is the main position your child plays?_____________________________

5. Has your child ever broken their forearm, upper arm, collarbone, or shoulder blade?
No_________
Yes_________
If yes, explain?____
______

6. Has your child ever had surgery on their elbow or shoulder?
No_________
Yes_________
If yes, explain?____
______

7. Has your child ever had a subluxation/dislocation of their elbow or shoulder?
No_________
Yes_________
If yes, explain?____
______

8. In the past 6 months has your child injured their elbow or shoulder that required a visit to a physician?
No__________
Yes_________
If yes, explain?____
______

9. Please list all teams played on in past year with an estimation of months played for each.
____
____
____
____
____
____

Please indicate any medical and/or health concerns you may have which have not been addressed by the previous items on this form. If there are any questions please feel free to contact one of the investigators at the following:

Matthew M Astolfi, B.S., ATC/L
541 South College Ave
University of Delaware
Newark, DE 19716   (607) 346-4496

____
Signature of participant   Date

____
Signature of parent/guardian   Date

____
Signature of Investigator   Date

Appendix B

INSTITUTIONAL REVIEW BOARD LETTER OF APPROVAL

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	February 11, 2013
TO:	Matthew Astolfi
FROM:	University of Delaware IRB
STUDY TITLE:	[328940-2] Shoulder Adaptations to Overhead Throwing in the Little League Athlete
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	February 11, 2013
EXPIRATION DATE:	April 17, 2013
REVIEW TYPE:	Expedited Review

Thank you for your submission of Amendment/Modification materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

Appendix C

DATA TABLES

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	35	5.0000	8.0000	13.0000	10.942857	1.3491360
Age_Group	35	1.0000	1.0000	2.0000	1.428571	.5020964
Dom_IR	35	46.0000	41.5000	87.5000	61.928571	12.0068258
Dom_ER	35	55.5000	124.0000	179.5000	152.471429	14.0842752
Dom_PST	35	9.2500	2.7500	12.0000	7.028571	2.0702474
Dom_PCT	35	.1250	.0650	.1900	.129429	.0238800
Dom_SAS	15	1.0000	.7450	1.7450	1.153000	.3645388
Dom_HR	35	48.5000	-32.0000	16.5000	-11.178571	13.3908402
NDom_IR	35	36.5000	58.0000	94.5000	75.100000	8.4963660
NDom_ER	35	50.5000	102.0000	152.5000	131.500000	12.1401134
NDom_PST	35	12.5000	.5000	13.0000	6.400000	3.0408977
NDom_PCT	35	.0950	.0850	.1800	.118286	.0184687
NDom_SAS	16	1.4800	.6900	2.1700	1.271563	.4122852
NDom_HR	35	48.5000	-44.5000	4.0000	-24.042857	10.5839581
Yrs_Played	35	8.0000	1.0000	9.0000	6.000000	1.7656860
Valid N (listwise)	13					

Correlations

		Dom_IR	Dom_ER	Dom_PST	Dom_PCT	Dom_SAS	Dom_HR	Yrs_Played
Dom_IR	Pearson Correlation	1	-.395*	.052	.222	.371	-.431**	-.024
	Sig. (2-tailed)		.019	.769	.200	.173	.010	.890
	N	35	35	35	35	15	35	35
Dom_ER	Pearson Correlation	-.395*	1	-.264	.322	-.200	.448**	-.109
	Sig. (2-tailed)	.019		.125	.059	.475	.007	.534
	N	35	35	35	35	15	35	35
Dom_PST	Pearson Correlation	.052	-.264	1	.044	.531*	-.232	-.165
	Sig. (2-tailed)	.769	.125		.801	.042	.179	.344
	N	35	35	35	35	15	35	35
Dom_PCT	Pearson Correlation	.222	.322	.044	1	.346	-.041	.167
	Sig. (2-tailed)	.200	.059	.801		.206	.817	.336
	N	35	35	35	35	15	35	35
Dom_SAS	Pearson Correlation	.371	-.200	.531*	.346	1	-.311	.306
	Sig. (2-tailed)	.173	.475	.042	.206		.259	.267
	N	15	15	15	15	15	15	15
Dom_HR	Pearson Correlation	-.431**	.448**	-.232	-.041	-.311	1	-.013
	Sig. (2-tailed)	.010	.007	.179	.817	.259		.939
	N	35	35	35	35	15	35	35
Yrs_Played	Pearson Correlation	-.024	-.109	-.165	.167	.306	-.013	1
	Sig. (2-tailed)	.890	.534	.344	.336	.267	.939	
	N	35	35	35	35	15	35	35

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		NDom_IR	NDom_ER	NDom_PST	NDom_PCT	NDom_SAS	NDom_HR	Yrs_Played
NDom_IR	Pearson Correlation	1	-.267	-.248	.045	.178	-.334*	.244
	Sig. (2-tailed)		.121	.151	.799	.509	.050	.158
	N	35	35	35	35	16	35	35
NDom_ER	Pearson Correlation	-.267	1	-.126	.234	-.256	.210	-.205
	Sig. (2-tailed)	.121		.469	.176	.339	.225	.237
	N	35	35	35	35	16	35	35
NDom_PST	Pearson Correlation	-.248	-.126	1	.180	.256	.047	-.088
	Sig. (2-tailed)	.151	.469		.300	.339	.788	.617
	N	35	35	35	35	16	35	35
NDom_PCT	Pearson Correlation	.045	.234	.180	1	.275	-.087	.352*
	Sig. (2-tailed)	.799	.176	.300		.303	.620	.038
	N	35	35	35	35	16	35	35
NDom_SAS	Pearson Correlation	.178	-.256	.256	.275	1	.006	.079
	Sig. (2-tailed)	.509	.339	.339	.303		.981	.771
	N	16	16	16	16	16	16	16
NDom_HR	Pearson Correlation	-.334*	.210	.047	-.087	.006	1	-.257
	Sig. (2-tailed)	.050	.225	.788	.620	.981		.136
	N	35	35	35	35	16	35	35
Yrs_Played	Pearson Correlation	.244	-.205	-.088	.352*	.079	-.257	1
	Sig. (2-tailed)	.158	.237	.617	.038	.771	.136	
	N	35	35	35	35	16	35	35

*. Correlation is significant at the 0.05 level (2-tailed).

Within-Subjects Factors

Measure: MEASURE_1

IR	Dependent Variable
1	Dom_IR
2	NDom_IR

Between-Subjects Factors

		N
Age_Group	1.0000	20
	2.0000	15

Descriptive Statistics

	Age_Group	Mean	Std. Deviation	N
Dom_IR	1.0000	60.200000	12.7860944	20
	2.0000	64.233333	10.8757047	15
	Total	61.928571	12.0068258	35
NDom_IR	1.0000	76.350000	9.1953936	20
	2.0000	73.433333	7.4399181	15
	Total	75.100000	8.4963660	35

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
IR	Sphericity Assumed	2754.096	1	2754.096	54.825	.000	54.825	1.000
	Greenhouse-Geisser	2754.096	1.000	2754.096	54.825	.000	54.825	1.000
	Huynh-Feldt	2754.096	1.000	2754.096	54.825	.000	54.825	1.000
	Lower-bound	2754.096	1.000	2754.096	54.825	.000	54.825	1.000
IR * Age_Group	Sphericity Assumed	207.011	1	207.011	4.121	.050	4.121	.504
	Greenhouse-Geisser	207.011	1.000	207.011	4.121	.050	4.121	.504
	Huynh-Feldt	207.011	1.000	207.011	4.121	.050	4.121	.504
	Lower-bound	207.011	1.000	207.011	4.121	.050	4.121	.504
Error(IR)	Sphericity Assumed	1657.725	33	50.234				
	Greenhouse-Geisser	1657.725	33.000	50.234				
	Huynh-Feldt	1657.725	33.000	50.234				
	Lower-bound	1657.725	33.000	50.234				

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	322263.344	1	322263.344	1938.553	.000	1938.553	1.000
Age_Group	5.344	1	5.344	.032	.859	.032	.053
Error	5485.892	33	166.239				

a. Computed using alpha = .05

Within-Subjects Factors

Measure: MEASURE_1

ER	Dependent Variable
1	Dom_ER
2	NDom_ER

Between-Subjects Factors

		N
Age_Group	1.0000	20
	2.0000	15

Descriptive Statistics

	Age_Group	Mean	Std. Deviation	N
Dom_ER	1.0000	151.200000	14.2647892	20
	2.0000	154.166667	14.1492891	15
	Total	152.471429	14.0842752	35
NDom_ER	1.0000	127.650000	12.4140201	20
	2.0000	136.633333	9.9686413	15
	Total	131.500000	12.1401134	35

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
ER	Sphericity Assumed	7233.601	1	7233.601	116.637	.000	116.637	1.000
	Greenhouse-Geisser	7233.601	1.000	7233.601	116.637	.000	116.637	1.000
	Huynh-Feldt	7233.601	1.000	7233.601	116.637	.000	116.637	1.000
	Lower-bound	7233.601	1.000	7233.601	116.637	.000	116.637	1.000
ER * Age_Group	Sphericity Assumed	155.144	1	155.144	2.502	.123	2.502	.336
	Greenhouse-Geisser	155.144	1.000	155.144	2.502	.123	2.502	.336
	Huynh-Feldt	155.144	1.000	155.144	2.502	.123	2.502	.336
	Lower-bound	155.144	1.000	155.144	2.502	.123	2.502	.336
Error(ER)	Sphericity Assumed	2046.592	33	62.018				
	Greenhouse-Geisser	2046.592	33.000	62.018				
	Huynh-Feldt	2046.592	33.000	62.018				
	Lower-bound	2046.592	33.000	62.018				

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	1390719.096	1	1390719.096	5132.537	.000	5132.537	1.000
Age_Group	612.011	1	612.011	2.259	.142	2.259	.309
Error	8941.725	33	270.961				

a. Computed using alpha = .05

Within-Subjects Factors

Measure: MEASURE_1

PST	Dependent Variable
1	Dom_PST
2	NDom_PST

Between-Subjects Factors

		N
Age_Group	1.0000	20
	2.0000	15

Descriptive Statistics

	Age_Group	Mean	Std. Deviation	N
Dom_PST	1.0000	7.175000	2.4266882	20
	2.0000	6.833333	1.5314170	15
	Total	7.028571	2.0702474	35
NDom_PST	1.0000	6.387500	3.4273235	20
	2.0000	6.416667	2.5524265	15
	Total	6.400000	3.0408977	35

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PST	Sphericity Assumed	6.214	1	6.214	1.841	.184	1.841	.261
	Greenhouse-Geisser	6.214	1.000	6.214	1.841	.184	1.841	.261
	Huynh-Feldt	6.214	1.000	6.214	1.841	.184	1.841	.261
	Lower-bound	6.214	1.000	6.214	1.841	.184	1.841	.261
PST * Age_Group	Sphericity Assumed	.589	1	.589	.175	.679	.175	.069
	Greenhouse-Geisser	.589	1.000	.589	.175	.679	.175	.069
	Huynh-Feldt	.589	1.000	.589	.175	.679	.175	.069
	Lower-bound	.589	1.000	.589	.175	.679	.175	.069
Error(PST)	Sphericity Assumed	111.371	33	3.375				
	Greenhouse-Geisser	111.371	33.000	3.375				
	Huynh-Feldt	111.371	33.000	3.375				
	Lower-bound	111.371	33.000	3.375				

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	3081.044	1	3081.044	292.385	.000	292.385	1.000
Age_Group	.419	1	.419	.040	.843	.040	.054
Error	347.742	33	10.538				

a. Computed using alpha = .05

Within-Subjects Factors

Measure: MEASURE_1

HR	Dependent Variable
1	Dom_HR
2	NDom_HR

Between-Subjects Factors

		N
Age_Group	1.0000	20
	2.0000	15

Descriptive Statistics

	Age_Group	Mean	Std. Deviation	N
Dom_HR	1.0000	-11.425000	13.8443177	20
	2.0000	-10.850000	13.2347621	15
	Total	-11.178571	13.3908402	35
NDom_HR	1.0000	-25.850000	10.5370274	20
	2.0000	-21.633333	10.5109920	15
	Total	-24.042857	10.5839581	35

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
HR	Sphericity Assumed	2723.400	1	2723.400	25.517	.000	25.517	.998
	Greenhouse-Geisser	2723.400	1.000	2723.400	25.517	.000	25.517	.998
	Huynh-Feldt	2723.400	1.000	2723.400	25.517	.000	25.517	.998
	Lower-bound	2723.400	1.000	2723.400	25.517	.000	25.517	.998
HR * Age_Group	Sphericity Assumed	56.836	1	56.836	.533	.471	.533	.109
	Greenhouse-Geisser	56.836	1.000	56.836	.533	.471	.533	.109
	Huynh-Feldt	56.836	1.000	56.836	.533	.471	.533	.109
	Lower-bound	56.836	1.000	56.836	.533	.471	.533	.109
Error(HR)	Sphericity Assumed	3521.998	33	106.727				
	Greenhouse-Geisser	3521.998	33.000	106.727				
	Huynh-Feldt	3521.998	33.000	106.727				
	Lower-bound	3521.998	33.000	106.727				

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	20855.250	1	20855.250	110.502	.000	110.502	1.000
Age_Group	98.400	1	98.400	.521	.475	.521	.108
Error	6228.148	33	188.732				

a. Computed using alpha = .05

Within-Subjects Factors

Measure: MEASURE_1

PCT	Dependent Variable
1	Dom_PCT
2	NDom_PCT

Between-Subjects Factors

		N
Age_Group	1.0000	20
	2.0000	15

Descriptive Statistics

	Age_Group	Mean	Std. Deviation	N
Dom_PCT	1.0000	.129750	.0238126	20
	2.0000	.129000	.0247992	15
	Total	.129429	.0238800	35
NDom_PCT	1.0000	.122750	.0206139	20
	2.0000	.112333	.0136102	15
	Total	.118286	.0184687	35

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
PCT	Sphericity Assumed	.002	1	.002	9.869	.004	9.869	.862
	Greenhouse-Geisser	.002	1.000	.002	9.869	.004	9.869	.862
	Huynh-Feldt	.002	1.000	.002	9.869	.004	9.869	.862
	Lower-bound	.002	1.000	.002	9.869	.004	9.869	.862
PCT * Age_Group	Sphericity Assumed	.000	1	.000	1.646	.208	1.646	.238
	Greenhouse-Geisser	.000	1.000	.000	1.646	.208	1.646	.238
	Huynh-Feldt	.000	1.000	.000	1.646	.208	1.646	.238
	Lower-bound	.000	1.000	.000	1.646	.208	1.646	.238
Error(PCT)	Sphericity Assumed	.008	33	.000				
	Greenhouse-Geisser	.008	33.000	.000				
	Huynh-Feldt	.008	33.000	.000				
	Lower-bound	.008	33.000	.000				

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	1.045	1	1.045	1566.024	.000	1566.024	1.000
Age_Group	.001	1	.001	.801	.377	.801	.140
Error	.022	33	.001				

a. Computed using alpha = .05