Journal of Athletic Training 2011:46(3):282–288

www.nata.org/jat

A Profile of Glenohumeral Internal and External Rotation Motion in the Uninjured High School Baseball Pitcher, Part I: Motion

Wendy J. Hurd, PhD, PT, SCS*; Kevin M. Kaplan, MD†; Neal S. ElAttrache, MD†; Frank W. Jobe, MD†; Bernard F. Morrey, MD*; Kenton R. Kaufman, PhD, PE*

*Mayo Clinic, Rochester, MN; †Kerlan-Jobe Orthopedic Clinic, Los Angeles, CA

Context: The magnitude of motion that is normal for the throwing shoulder in uninjured baseball pitchers has not been established. Chronologic factors contributing to adaptations in motion present in the thrower's shoulder also have not been established.

Objectives: To develop a normative profile of glenohumeral rotation motion in uninjured high school baseball pitchers and to evaluate the effect of chronologic characteristics on the development of adaptations in shoulder rotation motion.

Design: Cohort study.

Setting: Baseball playing field.

Patients or Other Participants: A total of 210 uninjured male high school baseball pitchers (age = 16 ± 1.1 years, height = 1.8 ± 0.1 m, mass = 77.5 ± 11.2 kg, pitching experience = 6 ± 2.3 years).

Intervention(s): Using standard goniometric techniques, we measured passive rotational glenohumeral range of motion bilaterally with participants in the supine position.

Main Outcome Measure(s): Paired *t* tests were performed to identify differences in motion between limbs for the group. Analysis of variance and post hoc Tukey tests were conducted to identify differences in motion by age. Linear regressions were performed to determine the influence of chronologic factors on limb motion.

Results: Rotation motion characteristics for the population were established. We found no difference between sides for external rotation (ER) at 0° of abduction ($t_{209} = 0.658$, $P = .51$), but we found side-to-side differences in ER ($t_{209} = -13.012$, $P < .001$) and internal rotation ($t_{209} = 15.304$, $P < .001$) at 90° of abduction. Age at the time of testing was a significant negative predictor of ER motion for the dominant shoulder ($R^2 = 0.019$, $P = .049$) because less ER motion occurred at the dominant shoulder with advancing age. We found no differences in rotation motion in the dominant shoulder across ages ($F_{4,205}$ range, 0.451–1.730, $P > .05$).

Conclusions: This range-of-motion profile might be used to assist with the interpretation of normal and atypical shoulder rotation motion in this population. Chronologic characteristics of athletes had no influence on range-of-motion adaptations in the thrower's shoulder.

Key Words: shoulder, throwing, range of motion

Key Points

- A normative population profile for rotational shoulder motion in the uninjured high school pitcher has been established.
- Side-to-side differences existed with external rotation and internal rotation at 90° of abduction but not with external rotation at 0° of abduction.
- Age at the time of testing was a significant negative predictor of external rotation at 90° of abduction for the dominant shoulder but was not a significant predictor of internal rotation at 90° of abduction or total shoulder motion.
- The number of years the athletes had been pitchers and the ages at which the athletes began pitching did not account for a large portion of the variability in the dominant shoulder motions tested.

Among high school baseball players, the throwing shoulder is the most common site of injury (17%).[1] The act of pitching alone accounts for more than 13% of all injuries in this group.[1] Therefore, prevention and treatment of shoulder injuries in the high school pitcher are clinical priorities. When shoulder motion is impaired, its restoration is a key component of rehabilitation.[2,3] In the general population, normal motion is determined by the motion available in the uninjured limb. However, an increase in glenohumeral external rotation (ER) and a corresponding loss of internal rotation (IR) at 90° of abduction when the throwing and nonthrowing limbs are compared is well documented in the baseball athlete.[2–12] This shift in motion (ie, ER gain and IR loss) has been attributed to repetitive microtraumatic stresses placed on the shoulder during the throwing motion.[2,3] Adaptations in rotational shoulder motion manifest during adolescence in the uninjured baseball athlete, become more pronounced with advancing age, and are greater in pitchers than positional players.[9] Therefore, when assessing the thrower's shoulder, a simple bilateral comparison is not adequate for determining whether these athletes have "normal" shoulder motion.

Limitations are associated with side-to-side comparisons when determining whether a baseball athlete has impaired rotation motion. Investigators have linked asymmetric total motion, which is defined as glenohumeral IR loss or ER gain greater than 5º on bilateral comparison, with shoulder lesions in the baseball athlete.[5,13] However, these studies were retrospective. Consequently, it is unclear whether asymmetric total motion is a risk factor contributing to injury or a response to injury. In the athlete with symmetric total motion, it is unclear if or at what point the magnitude of IR loss and ER gain becomes a risk factor for injury. Tightness of the posterior soft tissue structures causing IR deficit might contribute to an increase in anterior humeral head translation.[2,3] Excessive ER as a consequence of anterior shoulder laxity might result in similar humeral head kinematics. Although considered normal adaptations in the overhead athlete, these soft tissue imbalances and joint pathomechanics have been implicated in throwing injuries, including functional (anterior) shoulder instability and internal impingement.[2,3] Development of a normative population data set for glenohumeral ER and IR motion is necessary to aid in the interpretation of shoulder range-of-motion measurements for the baseball athlete.

Researchers have described shoulder motion for large samples of youth baseball athletes. Meister et al[8] reported shoulder motion in 294 uninjured baseball players aged 8 to 16 years. Levine et al[9] reported shoulder range of motion in 298 uninjured baseball athletes aged 8 to 28 years. Consistent with previous reports, both groups of investigators reported increases in ER and losses of IR at 90º of abduction in the throwing limb compared with the nonthrowing limb.[8,9] Although they studied large samples, Meister et al[8] and Levine et al[9] included a broad range of ages and did not discriminate between pitchers and positional players. Therefore, these studies have limited usefulness in establishing a normative profile of shoulder motion in the high school baseball pitcher.

Factors contributing to adaptations in shoulder motion are unclear. In a study of professional baseball athletes, Bigliani et al[12] reported no relationship between the age of the player or years of professional career and shoulder range of motion. In contrast, Meister et al[8] and Levine et al[9] each reported more pronounced adaptations in shoulder motion with advancing age among adolescent baseball players. However, they did not perform statistical tests to evaluate the relationship between age and motion.[8,9] Thus, the influence of age and years of sports experience on shoulder motion remains unclear. Identification of a relationship between chronologic factors contributing to adaptations in motion might provide further insight into athletes who may be at risk for shoulder injury.

For rehabilitation specialists attempting to identify athletes at risk for injury or determining readiness for sport participation after an injury, establishing normal shoulder motion to promote successful (ie, injury-free) sport participation is critical. Therefore, the primary purpose of our study was to develop a normative profile of glenohumeral rotation motion in uninjured high school baseball pitchers, including ER at 0º of abduction and IR and ER at 90º of abduction. The secondary purpose of our study was to evaluate chronologic characteristics, including age at the time of testing, number of years competing as a pitcher, and age at which athletes began pitching, to determine what effect these factors have on the development of adaptations in shoulder rotation motion.

METHODS

Participants

Two hundred ten male high school baseball pitchers (age = 16 ± 1.1 years, range, 14–18 years; height = 1.8 ± 0.1 m, range 1.6–2.0 m; mass = 77.5 ± 11.2 kg, range, 54.4–107.3 kg) were recruited from Minnesota, California, and Arizona. Average experience as a pitcher was 6 ± 2.3 years (range, 3–14 years). Forty-eight athletes were left-hand dominant, and 162 were right-hand dominant. We defined the *dominant arm* as the arm with which the athlete threw a ball. To be eligible for study participation, the athletes were required to be 14 to 18 years old and to have pitched competitively in organized baseball in any capacity for the 3 consecutive years before the study. People reporting that they played multiple positions could participate, but their primary position had to be pitcher. Participants also had to be unrestricted in baseball activities and to have no upper extremity injury at the time of testing. They completed the *Quick*DASH Outcome Measure (Institute for Work & Health, Toronto, ON), which is a shortened version of the Disabilities of the Arm, Shoulder and Hand Outcome Measure (DASH; Institute for Work & Health). The *Quick*DASH is an 11-item self-assessment instrument that instructs participants to rate their abilities to perform daily, work, and sporting activities on a 5-point scale, ranging from 1 (*no difficulty*) to 5 (*unable*). It has been found to be a reliable substitute for the DASH for the assessment of upper extremity function.[14] A *Quick*DASH sports score of 10% or lower was required to ensure that the athletes were not limited in baseball participation secondary to symptoms affecting the throwing limb. A physical examination of both upper extremities was conducted by either a board-certified sports physical therapist (W.J.H.) or a fellowship-trained orthopaedic surgeon (K.M.K.) to confirm the absence of injury to either limb. Athletes who did not meet all eligibility criteria were disqualified from study participation. Age groups differed by mass, years of pitching experience, and number of participants per group (Table 1). We found no difference in height across age groups. Participants and parents provided written informed consent, and the study was approved by the Mayo Clinic Institutional Review Board.

Table 1. Demographics by Age

	Limb Dominance, No.		Height, m		Mass, kg		Pitching Experience, y	
Age Group, y	Right	Left	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
14 (n = 23)	19	4	1.8 ± 0.1	1.6–2.0	67.7 ± 11.0	54.4–93.0	5 ± 1	3–8
15 (n = 42)	33	9	1.8 ± 0.1	1.7–2.0	72.1 ± 11.0	56.7–95.3	6 ± 2	3–9
16 (n = 66)	55	11	1.8 ± 0.1	1.7–2.0	81.5 ± 19.0	54.4–107.3	7 ± 2	3–12
17 (n = 63)	44	19	1.8 ± 0.1	1.7–2.0	79.8 ± 8.9	54.4–99.8	7 ± 2	3–12
18 (n = 16)	11	5	1.9 ± 0.1	1.7–1.9	83.0 ± 8.3	72.1–106.6	9 ± 2	6–14

Procedures

A 5- to 10-minute warmup consisting of stretching, jogging, and short-toss activities was performed before testing began. Next, passive shoulder range of motion was conducted in a standardized order, including ER at 0º of abduction, ER at 90º of abduction, and IR at 90º of abduction on the right limb followed by the left limb. A single examiner conducted all tests. The examiner stabilized the glenohumeral joint by placing the palm of 1 hand on the anterior aspect of the shoulder over the clavicle, coracoid process, and humeral head.[4] Next, the participant's limb was taken through a full arc of passive range of motion until an end point was reached. *End of motion* was defined as a cessation of motion or the point at which scapular movement was appreciated.[13] An assistant positioned the goniometer and recorded the end-point shoulder angle. The examiner was blinded to all measurements.

All tests were conducted with participants lying supine and a towel roll positioned under the humerus to align the upper limb in a neutral position (humerus level with the acromion process).[13,15] Shoulder range of motion was measured using a standard, long-arm goniometer with a bubble level secured to the stationary arm to assist with device alignment.[4,8,13] Measurements were performed using standard goniometric techniques as described by Norkin and White[15]; the axis of the device was aligned with the olecranon, the moving arm was parallel to the forearm in alignment with the ulnar styloid process, and the reference arm was perpendicular to the ceiling (ER at 0º of abduction) or the floor (ER and IR at 90º of abduction). Two trials were performed for each motion of interest. Test-retest reliability was assessed in a sample (n = 10) of uninjured adults, and intraclass correlation coefficients ranged from 0.944 to 0.990 for all motions measured. Trial-to-trial variability for the motion measurements collected during the study was less than 5º.

Data Analyses

The peak values of the 2 trials for each motion were averaged and used for analysis. Descriptive statistics were calculated for the variables of interest, including ER at 0º of abduction, ER at 90º of abduction, and IR at 90º of abduction for each limb. In addition, the total arc of rotation motion was calculated for each limb by adding ER and IR measured at 90º of abduction. As Wilk et al[2] described, the total motion concept is an alternative means of evaluating glenohumeral rotation in the baseball athlete. This method defines normal motion as a loss of IR motion that is equivalent to the gain in ER. The total motion assessment technique permits within-person side-to-side comparisons to establish what normal shoulder motion is for each person. The throwing shoulder is considered equal to the nonthrowing shoulder when a side-to-side difference of 5º or less exists.[2] Paired *t* tests were performed to analyze motion between limbs for the group. An analysis of variance (ANOVA) was performed to analyze motion by age. When differences were identified, pairwise comparisons were performed using a post hoc Tukey test. Linear regressions were performed to determine the influence of participant age, number of years of pitching experience, and age at which the participant began pitching on limb motion. The α level was set a priori at .05. We used SPSS (version 19; SPSS Inc, Chicago, IL) for statistical analysis.

RESULTS

For the group, we found no side-to-side differences in ER at 0º of abduction ($t_{209} = 0.658$, $P = .51$) (Table 2). We found side-to-side differences in ER ($t_{209} = -13.012$, $P < .001$) and IR ($t_{209} = 15.304$, $P < .001$) at 90º of abduction because ER increased an average of 10º and IR decreased an average of 15º in the dominant limb compared with the nondominant limb (Table 2). We found a difference in total shoulder rotation motion ($t_{209} = -4.098$, $P < .001$) when comparing limbs, but this difference was 5º (Table 2).

For the group, participant age at the time of testing was a significant negative predictor of ER at 90º for the dominant shoulder ($R^2 = 0.019$, $P = .049$) because ER decreased in the dominant shoulder with advancing age; however, the amount of variability accounted for by the participant's age was small, as indicated by the R^2 value (Table 3). Age at the time of testing was not a significant predictor of IR at 90º of abduction or total shoulder rotation motion. The number of years of pitching experience and the age at which participants began pitching did not account for a large portion of the variability in any of the dominant shoulder motions tested (Table 3).

We found no differences in dominant-limb shoulder motion by age (Table 4; Figure). We found a difference across age groups in nondominant-limb motion at 90º of abduction for ER ($F_{4,205} = 2.738$, $P = .03$), IR ($F_{4,205} = 4.783$, $P = .001$), and total motion ($F_{4,205} = 5.283$, $P < .001$) (Table 4; Figure). Post hoc analysis indicated that ER at 90º of abduction was greater in the 15-year-old group than the 17-year-old group. Internal rotation at 90º of abduction was greater in the 16-year-old group than the 17-year-old group. Total motion measured at 90º of abduction was greater in both the 15- and 16-year-old groups than in the 17-year-old group.

Table 2. Group Side-to-Side Range of Motion

	Limb					
	Dominant		Nondominant			
Range of Motion	Mean ± SD, °	90% Confidence Interval, °	Mean ± SD, °	90% Confidence Interval, °	*P* Value	t_{209} Value
External rotation at 0º of abduction	84 ± 11	64, 101	84 ± 10	67, 100	.51	0.658
External rotation at 90º of abduction	130 ± 11	113, 148	120 ± 10	100, 136	<.001[a]	–13.012
Internal rotation at 90º of abduction	60 ± 11	41, 80	75 ± 11	55, 91	<.001[a]	15.304
Total motion	190 ± 15	166, 216	195 ± 15	168, 218	<.001[a]	–4.098

[a] Indicates difference.

Table 3. Influence of Age at Testing, Years of Pitching Experience, and Age at Which Athlete Began Pitching on Dominant Limb Motion at 90º of Abduction

Variable	R^2	P Value
Age at testing		
External rotation	0.019	.049[a]
Internal rotation	0.002	.52
Total motion	0.018	.05
Years of pitching experience		
External rotation	<0.001	.89
Internal rotation	0.001	.65
Total motion	<0.001	.80
Age at which athlete began pitching		
External rotation	0.007	.22
Internal rotation	<0.001	.88
Total motion	0.003	.44

[a] Indicates difference ($P<.05$).

Table 4. Analysis of Variance for Comparison of Motion Across Age Groups

Range of Motion	Limb	$F_{4,205}$ Value	P Value
External rotation at 0° of abduction	Dominant	0.451	.77
	Nondominant	1.645	.16
External rotation at 90° of abduction	Dominant	1.730	.15
	Nondominant	2.738	.03[a]
Internal rotation at 90° of abduction	Dominant	0.475	.75
	Nondominant	4.783	.001[a]
Total motion	Dominant	1.598	.18
	Nondominant	5.283	<.001[a]

[a] Indicates difference ($P<.05$).

DISCUSSION

Our results provide a profile of glenohumeral rotation motion for the uninjured high school baseball pitcher. Establishing the range and average values for internal and external shoulder motion in this population was possible because of the large sample size and participant homogeneity relative to position and level of play. This normative database might be useful in assisting with the interpretation of shoulder range of motion and guiding athlete care after rehabilitation of an injury or during performance enhancement evaluation.[16] Earlier definitions of normal shoulder motion in the baseball athlete were based on summed IR and ER within 5º on bilateral comparison. This method of defining normal motion is limited because it does not permit an assessment of ER or IR in isolation. If a bilateral difference in total motion exceeds 5º, which motion is limited might be unclear. Alternatively, total motion that is deemed symmetric might mask abnormal motion. For example, an athlete might have symmetric total motion in the presence of above-average IR and limited ER. This limitation in ER might contribute to pain during throwing or compromised sport performance. Therefore, we advocate the use of the normative population data established in our study and a bilateral comparison of total motion when interpreting shoulder motion in the baseball pitcher.

The magnitude of side-to-side differences in motion that we identified is comparable to that identified by previous researchers, who described shoulder motion in the youth baseball athlete. Reports of ER gain in the throwing shoulder compared with the nonthrowing shoulder in the adolescent player have ranged from 6º to 11º, and reports of IR loss have ranged from 2º to 13º.[8,9,17] Bilateral comparisons have indicated that the limbs are symmetric relative to total rotation motion, with side-to-side differences averaging less than 5º.[8,9,17] In comparison, we identified an average 10º ER gain and 15º IR loss when comparing the throwing and nonthrowing shoulders. Although we identified a difference in total motion when comparing limbs, it was less than 5º and was not considered clinically meaningful.

In contrast, larger ranges of glenohumeral IR and ER motion have been reported for uninjured youth baseball players (Table 5). One potential source of this disparity might be the participants' ages included in the studies. Meister et al[8] reported a decrease in total motion with advancing age when evaluating passive glenohumeral rotation in youth baseball athletes, with the most dramatic decline observed between 13- and 14-year-old athletes. Levine et al[9] did not evaluate differences in the magnitude of ER and IR motion in the dominant shoulder across age groups. However, visual inspection suggests they found clinically meaningful differences in motion between participants aged 8 to 12 years and participants aged 13 to 28 years. The results reported by Meister et al[8] and Levine et al[9] emphasize the importance of evaluating motion in a group of participants who are of equivalent physical maturity. Although we did not collect radiographic data to evaluate skeletal maturity, we found a difference of less than 5º between the 14- and 18-year-old participants for each motion assessed at both extremities. Furthermore, age at the time of testing was not a meaningful predictor of shoulder motion. This suggests that all the high school baseball pitchers (14 to 18 years) were appropriately considered as a single group.

Methodologic differences also might contribute to the range of values that has been described for shoulder motion in youth baseball athletes. We measured motion after the participants completed a warmup. This might explain, in part, why the average glenohumeral motions we reported were greater than values reported by previous investigators. However, a warmup process often is neglected in studies in which upper extremity range of motion is assessed. Peterson et al[18] measured passive shoulder ER motion in tennis players before and after a sport-specific warmup, which consisted of stretching, practice swings, and serves. They reported an increase of 7º in ER motion after the warmup. In addition, the investigators reported a difference when comparing the motion obtained during the first trial with that obtained during the third trial for both testing sessions. They concluded that shoulder range of motion is dynamic when the limb is cold.[18] We incorporated a comparable sport-specific warmup. We believe this aspect of the testing protocol allowed us to capture the true extensibility of the shoulder joint. A potential limitation of our study that might have affected the results was that we did not randomize the testing order. The soft tissue extensibility gained after the warmup might have been compromised in motions assessed at the end of the testing session. However, the time needed to complete the protocol was, on average, less than 10 minutes. Therefore, we do not believe the failure to randomize the testing order had a great effect on shoulder motion. Confirming the effect of testing sequence on shoulder mobility in this population is difficult because previous investigators[5,8,9] used similar testing sequences to assess shoulder motion.

Shoulder stabilization technique is another methodologic component that might contribute to the disparity in shoulder motion reported for the baseball athlete. Wilk et al[4] evaluated the effects of 3 stabilization approaches on shoulder IR mo-

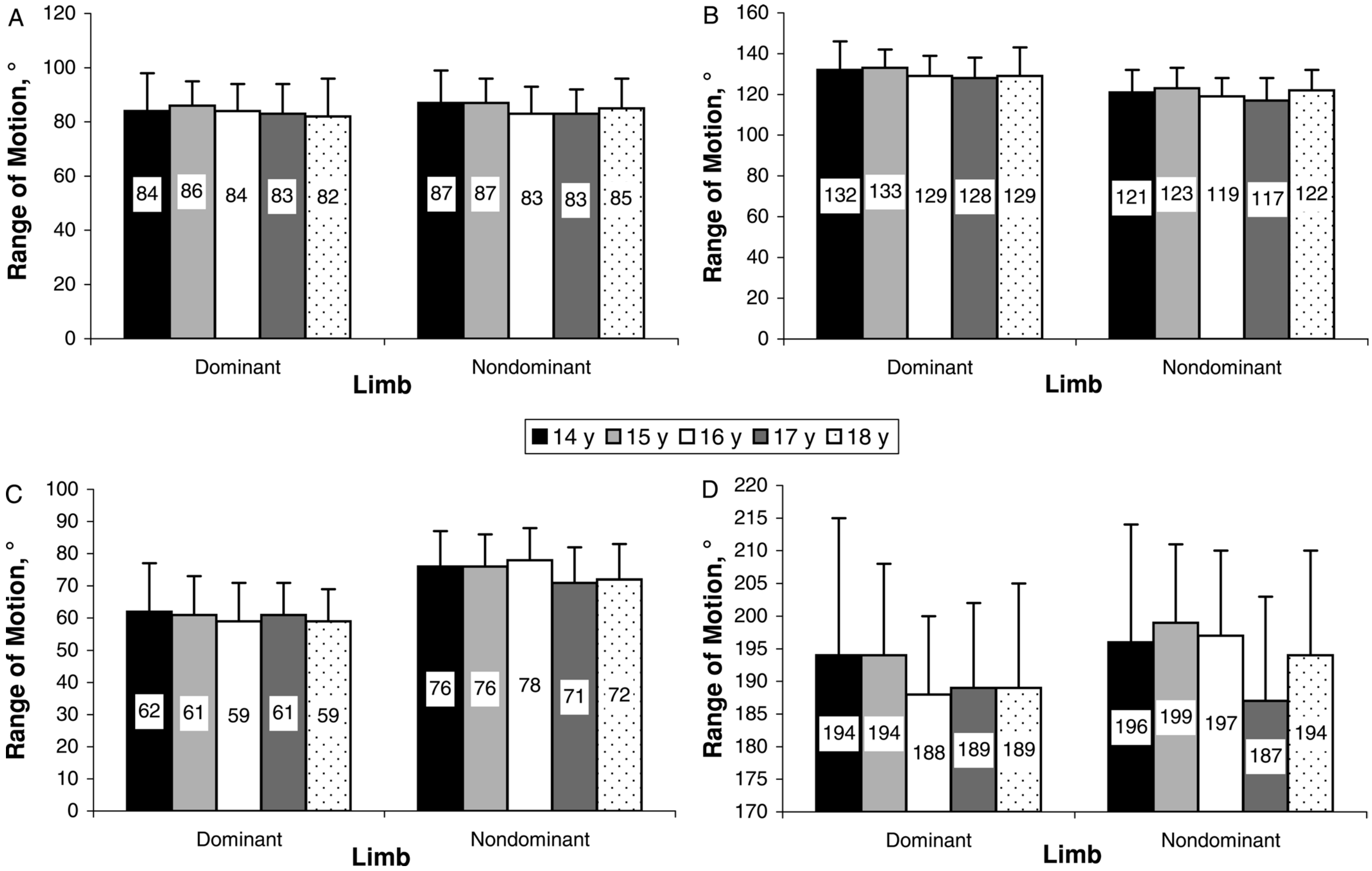

Figure. Range of motion for the dominant and nondominant limbs by age group. A, External rotation at 0° of abduction. B, External rotation at 90° of abduction. C, Internal rotation at 90° of abduction. D, Total rotation motion at 90° of abduction.

Table 5. Comparison of Mean Shoulder Motion in Youth Baseball Athletes Across Studies

Investigation	Participant Age Range, y	External Rotation at 90° of Abduction, °	Internal Rotation at 90° of Abduction, °
Our study	14–18	130	60
Meister et al[8]	8–16	143	36
Levine et al[9]	8–12	96	33
Levine et al[9]	13–14	115	40
Levine et al[9]	15–28	109	38

tion, including visual inspection of substitution to identify the motion endpoint with no shoulder stabilization; stabilization by placing the palm over the clavicle, coracoid process, and humeral head (the method we used); and stabilization by grasping the coracoid process and the spine of the scapula posteriorly. They reported differences in motion based on shoulder stabilization technique and suggested the use of a standardized approach to allow clinicians to compare patient findings and researchers to compare data. The authors advocated the use of the stabilization technique that included grasping the coracoid process and the spine of the scapula posteriorly.[4] The rationale was that this technique permitted adequate stabilization with the least effect on glenohumeral arthrokinematics. However, the authors did not have 3-dimensional data to support this statement. Furthermore, we found it difficult for a single examiner to adequately stabilize the shoulder with this approach and take the limb through a full range of motion. Consequently, we chose to stabilize the shoulder with an anterior placement of the examiner's hand. In future applications of the normative data we described, researchers should attempt to replicate the methods for comparisons to be valid.

We found no side-to-side differences in motion when measuring ER at 0° of abduction. Few researchers have described ER motion with the limb by the side among a sample of baseball athletes because motion in the throwing position in this population is of greater interest. Reagan et al[7] measured glenohumeral range of motion and humeral retroversion in 54 asymptomatic collegiate baseball athletes. Although adaptations occurred in rotation motion at the throwing shoulder with the limb in 90° of abduction, the side-to-side difference in ER with the limb by the side was less than 1°. In addition, no difference was found in IR motion measured with the limb by the side (using the spinal touch method). Reagan et al[7] did report a correlation between humeral head retroversion and rotation motion measured at 90° of abduction. These findings prompted them to conclude, in agreement with other investigators,[10,19,20] that the shift in rotation motion in the thrower's shoulder might be related more strongly to adaptive changes in osseous humeral anatomy than to changes in soft tissues. However, Reagan et al[7] did not comment on the absence of side-to-side differences at 0° of abduction or any relationships between humeral retroversion and shoulder rotation with the limb by the side. Given the large sample size and our primary purpose, we did not assess shoulder joint mobility or osseous anatomy. Future investigators should consider relationships between shoulder rotation motion and osseous anatomy with the limb in nonthrowing positions to gain further insight into mechanisms contributing to adaptations in the thrower's shoulder.

Speculating that specific capsular adaptations might be contributing to asymmetric shoulder motion as a consequence of throwing is reasonable. The anterior shoulder capsule is described as having 3 components: the superior, middle, and inferior glenohumeral ligaments, with the inferior glenohumeral ligament composed of anterior and posterior bands.[21–23] The anterior band of the inferior glenohumeral ligament limits anterior humeral head translation when the limb is abducted to 90º, which is the throwing position.[24] In contrast, the superior and middle glenohumeral ligaments are the primary restraints to anterior humeral head translation when the limb is in 0º of abduction.[25] Greater extensibility of the anterior band of the inferior glenohumeral ligament could explain, in part, why ER of the throwing limb increased in 90º of abduction but not when the limb was by the side.

However, researchers have indicated that adaptations in the anterior shoulder capsule are not the source of asymmetric shoulder motion in the baseball athlete. Using instrumented stress arthrometry, Borsa et al[11] measured bilateral passive shoulder stiffness in 34 asymptomatic professional baseball pitchers. They reported no difference in anterior joint stiffness between shoulders. In a separate study, Borsa et al[26] used ultrasound imaging to measure glenohumeral translation with the limb externally rotated to 90º of abduction in 43 asymptomatic professional baseball pitchers under stressed and nonstressed conditions. The investigators reported no differences in translation between the throwing and nonthrowing limbs. Borsa et al[26] concluded that these findings provided additional evidence to support the assertion that range-of-motion alterations are more likely because of osseous as opposed to capsular adaptations. The contribution of adaptations in osseous and soft tissue structures to the shift in rotation motion in the thrower's shoulder is unclear. The absence of side-to-side differences in rotation motion with the limb by the side suggests that the effect of these adaptations is dependent on limb position.

No differences existed in shoulder motion of the dominant limb across age groups. We found less motion in the nondominant limb of 17-year-old pitchers than in 15- and 16-year-old pitchers. Meister et al[8] reported a decline in IR shoulder motion for both limbs in baseball pitchers aged 8 to 16 years. The largest changes in rotation motion occurred between ages 12 and 13 years for the dominant limb and between ages 14 and 15 for the nondominant limb. They found no change in ER motion across ages. The authors hypothesized that the decrease in motion was a consequence of an increase in tissue stiffness associated with age-related increases in collagen. A modest decrease in shoulder motion with advancing age also has been found in nonthrowers. Jansson et al[27] studied shoulder range of motion and laxity in 1227 school children aged 9 to 12 years and reported that total rotation motion was 3º less in boys aged 12 years than in boys aged 9 years. It is possible that we did not observe greater differences in shoulder motion across age groups because of the more advanced age of the participants in our study. Interestingly, whereas the nondominant limb demonstrated less motion in athletes aged 17 years in our study than in younger athletes, the motion in the oldest participants (18 years) was not different from that in the youngest participants (14 years). The rationale for the decrease in motion for the 17-year-old group is unclear. It is possible that a transition occurred in training or sports participation at this age, contributing to changes in joint flexibility. Alternatively, we had few participants in our 18-year-old group (n = 16). A larger sample of participants this age might provide greater insight into adaptive changes in shoulder motion as baseball athletes reach their late teens. Longitudinal studies in which shoulder motion is tracked in the same athlete through maturation will provide the greatest insight into the effect of age and playing patterns on shoulder motion patterns.

None of the chronologic variables we evaluated had a meaningful effect on shoulder rotation motion. Furthermore, we did not find a difference in motion in the dominant limb across ages. The effects of the age at which the athlete began pitching, total years as a pitcher, and the athlete's age at the time of testing on shoulder motion remain controversial. In a study of professional baseball athletes, Bigliani et al[12] reported no relationship between the age of the player or years of professional career and shoulder range of motion. In contrast, Kibler et al[28] found a negative correlation between total range of motion in the dominant shoulder and years of tournament play in elite tennis players, who are overhead athletes exhibiting adaptations in shoulder motion comparable to those of baseball athletes. One potential source of the apparently contrasting findings is the average age of the athletes in the 2 studies. The athletes evaluated by Bigliani et al[12] had a mean age of 23 years and had been professional athletes for 3 years. Participants whom Kibler et al[28] studied had a mean age of 18 years and had been in tournament play for 8.8 years.

We believe the inability to capture the volume of throwing (or tennis) activities is a potential reason for the inconsistencies across studies in which the influence of athlete age and experience on shoulder motion were evaluated. Age and years of experience are intended to be indicators of how much throwing a given person has performed. The inference is that more experience participating in a given sport results in more repetitions of a given skill, yielding more pronounced adaptations. However, chronologic variables do not capture the number of pitches thrown or innings and leagues in which the athlete has participated. We do not believe these data might be obtained retrospectively with a high level of precision. Consequently, we advocate conducting studies to prospectively capture the volume of baseball activities to gain insight into factors contributing to adaptations in shoulder motion.

CONCLUSIONS

We evaluated shoulder motion in a large, homogeneous sample of high school baseball pitchers. The results obtained with this design provide a normative profile describing glenohumeral rotation motion for this population, which might be used to assist clinicians and researchers in the interpretation of shoulder rotation motion in this population. Our results are consistent with those of other researchers who described side-to-side differences in total rotation motion but did not identify an influence of athlete chronologic characteristics on range-of-motion adaptations in the thrower's shoulder.

REFERENCES

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

2. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. *Am J Sports Med*. 2002;30(1):136–151.
3. Wilk KE, Obma P, Simpson CD, Cain EL, Dugas JR, Andrews JR. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther*. 2009;39(2):38–54.
4. Wilk KE, Reinold MM, Macrina LC, et al. Glenohumeral internal rotation measurements differ depending on stabilization techniques. *Sports Health*. 2009;1(2):131–136.
5. Ruotolo C, Price E, Panchal A. Loss of total arc of motion in collegiate baseball players. *J Shoulder Elbow Surg*. 2006;15(1):67–71.
6. Reinold MM, Wilk KE, Macrina LC, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *Am J Sports Med*. 2008;36(3):523–527.
7. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med*. 2002;30(3):354–360.
8. Meister K, Day T, Horodyski M, Kaminski TW, Wasik MP, Tillman S. Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. *Am J Sports Med*. 2005;33(5):693–698.
9. Levine WN, Brandon ML, Stein BS, Gardner TR, Bigliani LU, Ahmad CS. Shoulder adaptive changes in youth baseball players. *J Shoulder Elbow Surg*. 2006;15(5):562–566.
10. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med*. 2002;30(1):20–26.
11. Borsa PA, Dover GC, Wilk KE, Reinold MM. Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc*. 2006;38(1):21–26.
12. Bigliani LU, Codd TP, Connor PM, Levine WN, Littlefield MA, Hershon SJ. Shoulder motion and laxity in the professional baseball player. *Am J Sports Med*. 1997;25(5):609–613.
13. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34(3):385–391.
14. Gummesson C, Ward MM, Atroshi I. The shortened Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH): validity and reliability based on responses within the full-length DASH. *BMC Musculoskelet Disord*. 2006;7:44.
15. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Geometry*. 3rd ed. Philadelphia, PA: FA Davis Company; 2003:34–37.
16. Ellenbecker TS, Roetert EP, Sueyoshi T, Riewald S. A descriptive profile of age-specific knee extension flexion strength in elite junior tennis players. *Br J Sports Med*. 2007;41(11):728–732.
17. Mair SD, Uhl TL, Robbe RG, Brindle KA. Physeal changes and range-of-motion differences in the dominant shoulders of skeletally immature baseball players. *J Shoulder Elbow Surg*. 2004;13(5):487–491.
18. Peterson DS, Wright JT, Grover GB, Tillman MD. Does warming up influence shoulder stiffness or external rotation in healthy, non-elite tennis players? *J Undergrad Res*. 2006;8(2). http://www.clas.ufl.edu/jur/200611/papers/paper_peterson.html. Accessed December 10, 2010.
19. Chant CB, Litchfield R, Griffin S, Thain LM. Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. *J Orthop Sports Phys Ther*. 2007;37(9):514–520.
20. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med*. 2002;30(3):347–353.
21. Wilk KE, Arrigo CA, Andrews JR. Current concepts: the stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther*. 1997;25(6):364–379.
22. Turkel SJ, Panio MW, Marshall JL, Girgis FG. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. *J Bone Joint Surg Am*. 1981;63(8):1208–1217.
23. O'Brien SJ, Neves MC, Arnoczky SP, et al. The anatomy and histology of the inferior glenohumeral ligament complex of the shoulder. *Am J Sports Med*. 1990;18(5):449–456.
24. O'Brien SJ, Schwartz RS, Warren RF, Torzilli PA. Capsular restraints to anterior-posterior motion of the abducted shoulder: a biomechanical study. *J Shoulder Elbow Surg*. 1995;4(4):298–308.
25. Bowen MK, Warren RF. Ligamentous control of shoulder stability based on selective cutting and static translation experiments. *Clin Sports Med*. 1991;10(4):757–782.
26. Borsa PA, Wilk KE, Jacobson JA, et al. Correlation of range of motion and glenohumeral translation in professional baseball pitchers. *Am J Sports Med*. 2005;33(9):1392–1399.
27. Jansson A, Saartok T, Werner S, Renstrom P. Evaluation of general joint laxity, shoulder laxity and mobility in competitive swimmers during growth and in normal controls. *Scand J Med Sci Sports*. 2005;15(3):169–176.
28. Kibler WB, Chandler TJ, Livingston BP, Roetert EP. Shoulder range of motion in elite tennis players: effect of age and years of tournament play. *Am J Sports Med*. 1996;24(3):279–285.

Address correspondence to Wendy J. Hurd, PhD, PT, SCS, Mayo Clinic, Charlton North Building, L110, Rochester, MN 19716. Address e-mail to hurd.wendy@mayo.edu.