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original research

Glenohumeral and Hip Range-of-Motion and Strength Measures in Youth Baseball Athletes

Kelsey J. Picha, MS*; Josie L. Harding, MS†; Kellie C. Huxel Bliven, PhD, ATC†

*University of Kentucky, Lexington; †A.T. Still University, Mesa, AZ

Context: The repetitive demands of throwing affect glenohumeral (GH) range of motion (ROM) and strength. Less is known about hip alterations in skeletally immature athletes.

Objective: To compare GH and hip ROM and strength between age, position, and side of youth baseball athletes.

Design: Cross-sectional study.

Setting: Multicenter testing.

Patients or Other Participants: Seventy-two healthy baseball athletes. Participants' self-reported age group (7–11 years [n = 28] or 12–18 years [n = 44]), position (pitcher [n = 22], position player [n = 47], unreported [n = 3]), and side (throwing or nonthrowing arm, lead or stance leg).

Main Outcome Measure(s): Bilateral GH and hip internal- and external-rotation ROM were measured passively and summed for total arc of motion (TAM). Glenohumeral and hip rotation and gluteus medius strength were measured. Analyses included linear mixed models.

Results: Glenohumeral internal rotation was less in throwing than in non-throwing arms ($P < .05$) except in younger pitchers ($P = .86$). Compared with older athletes, younger athletes had more GH external rotation (103.3° ± 7.7° versus 97.5° ± 9.4°; $P = .002$), TAM (156.4° ± 8.7° versus 147.9° ± 10.9°; $P = .04$), and external rotation in throwing compared with nonthrowing arms (101.9° ± 1.2° versus 97.9° ± 1.1°; $P < .001$). Glenohumeral TAM was less in throwing than in nonthrowing arms (150.5° ± 2.1° versus 154.9° ± 1.3°; $P = .01$). Younger athletes had more hip internal rotation (38.9° ± 6.8° versus 31.2° ± 7.5°; $P < .001$) and TAM (68.4° ± 10.0° versus 60.7° ± 9.8°; $P = .001$) than older athletes. Lead-leg hip internal-rotation ROM was greater than in the stance leg (34.8° ± 8.9° versus 32.8° ± 7.7°; $P = .01$). Overall, older players were stronger than younger players ($P < .05$), and the throwing arm was stronger in internal rotation than the nonthrowing arm (10.12 ± 3.72 kg versus 9.43 ± 3.18 kg; $P = .047$).

Conclusions: Youth baseball athletes had typical GH ROM adaptations of less internal rotation and more external rotation in the throwing versus the nonthrowing arm. Greater ROM in younger athletes may be explained by prepubertal characteristics. We obtained hip strength values in youth baseball athletes, and as expected, older athletes were stronger.

Key Words: shoulder, kinetic chain, adolescents, throwing athletes

Key Points

- Youth baseball athletes showed glenohumeral and hip adaptations between age groups.
- Glenohumeral range-of-motion adaptations typical in baseball athletes—less internal rotation and more external rotation—were present in participants as young as 8 years old.

Baseball is a popular American sport, and the number of participating athletes has increased in recent years. Between 2013 and 2014 in the high school setting, 482 629 boys played baseball.[1] Participating in this sport places high loads and repetitive forces through the shoulder, leading to range-of-motion (ROM) and strength adaptations that may affect young players whose growth plates have not yet closed. The humeral physis, for example, matures through adolescence with rapid growth from 13 to 16 years.[2] Although the force baseball athletes produce as they become stronger with age and maturation contributes to improved performance, it may also lead to injury at open ossification centers and affect humeral retroversion.

Glenohumeral (GH) ROM adaptations have been studied extensively in collegiate and professional baseball athletes,[3–5] but few authors have investigated adaptations in youth and high school baseball athletes.[2] The known shoulder ROM adaptations of baseball athletes include more external rotation and less internal rotation in the throwing arm compared with the nonthrowing arm.[2,6,7] When Shanley et al[8] compared high school baseball and softball athletes bilaterally, those who had 25° or greater loss of shoulder internal rotation in their throwing arm were 4 to 5 times more likely to develop an upper extremity injury. The authors also suggested that normative data for ROM in youth baseball athletes are needed because no data are currently available.[8] *Humeral retroversion* involves rotational twisting of the long axis of the humerus,[3,5,9] which may play a role in ROM changes in these baseball athletes. Other researchers[3,5] have found that humeral retroversion is greater in the throwing arm compared with the nonthrowing arm in adult baseball athletes. However, data about ROM adaptations in youth baseball athletes are lacking, so it is unknown when humeral retroversion begins and how quickly it develops.

Glenohumeral strength also changes with age, and the change is associated with increased injury risk. Increased strength and imbalances between internal- and external-rotation muscles may contribute to injury. Harada et al[10]

Table 1. Demographic Characteristics of Youth Baseball Athletes by Age Group (Mean ± SD)

	Characteristic			
Age Group	Age, y	Height, cm	Weight, kg	Competitive Play, y
7–11 y (n = 28)	9.8 ± 1.1	139.6 ± 13.3	37.3 ± 11.1	3.7 ± 1.1
12–18 y (n = 44)	15.4 ± 2.1	175.5 ± 12.6	68.7 ± 19.5	6.9 ± 2.9
All ages (n = 72)	12.8 ± 3.3	161.7± 21.4	56.5 ± 22.3	5.5 ± 2.8

identified a relationship between increased shoulder internal- and external-rotation strength and an increase in elbow injuries in baseball athletes aged 9 to 12 years. In a study of adolescent baseball pitchers, Trakis et al[11] suggested that overdeveloped anterior musculature (eg, internal rotators) and weakened posterior musculature (eg, external rotators and scapular stabilizers) may be associated with throwing-related pain. This imbalance of internal- and external-rotation musculature in the throwing arm may lead to soft tissue damage in the posterior shoulder, causing additional injury.

Even though the hip may not experience high impact forces when the athlete is playing baseball, it transmits energy and forces through the rest of the kinetic chain. Therefore, although ROM and strength adaptations may be necessary for improved performance, they are also risk factors for injury, particularly in skeletally immature athletes. The importance of the kinetic chain is well accepted, yet research examining its effect on shoulder injury, specifically hip ROM and strength, is limited to adult populations.[4,12,13] The hips play an important role in the throwing motion; effective lead-leg ROM is necessary to generate force through the upper extremity to produce greater ball velocity.[13,14] Investigation suggests a relationship between hip and shoulder ROM and shoulder injury; however, this relationship has not been found in healthy professional baseball athletes.[12] For pitchers and position athletes, Scher et al[4] found a moderate relationship between dominant-shoulder external-rotation ROM and nondominant hip-extension ROM in pitchers (r = .62) and nonpitchers (r = –.64) with a history of injury.

Poor hip strength may also contribute to throwing-related injury. Studies suggest that the gluteus medius helps stabilize the trail leg during the early phases of the throwing motion, and that weakness or altered activation of this muscle may decrease efficient force transfer to the upper extremity.[15,16] However, examinations of hip ROM and isometric strength in conjunction with shoulder injury have had inconsistent findings,[4,17,18] which may be attributable to isolated isometric tests and variability in test positions. Further, existing evidence on this topic is limited to adult populations and may not translate well to a youth population.

Screening youth baseball athletes before the start of the season may provide valuable information on potential risk factors for injury. Range of motion and strength are 2 measurements that should be used to identify deficits and risk factors. Therefore, the purpose of our study was to compare GH and hip ROM and strength measurements between age groups (7–11 years or 12–18 years), position (pitcher, position player), and side (throwing or nonthrowing arm, lead or stance leg) in youth baseball athletes. We hypothesized that our GH ROM measures, internal and external rotation, would be consistent with current research findings and that GH strength would increase with age. For the hip, we hypothesized that the lead leg would have greater ROM compared with the stance leg and that strength would increase with age.

METHODS

Design

This was a prospective, cross-sectional study comparing GH and hip ROM and strength in youth baseball athletes. Independent variables were age group (7–11 years or 12–18 years), position (pitcher, position player), and side (throwing or nonthrowing arm, lead or stance leg). Both shoulders and hips of participants were measured for the dependent variables of ROM and strength. For ROM, the GH and hip internal- and external-rotation ROM and the total arc of motion (TAM) were measured in degrees. For strength, the GH and hip internal rotation, external rotation, and gluteus medius were measured in kilograms (kg) of force.

Participants

We assessed a convenience sample of healthy male baseball athletes aged 7 to 18 years who were recruited from local youth baseball leagues and high schools in a metropolitan area (Table 1). Participants were placed in 1 of the 2 age groups for the study (7–11 years or 12–18 years) using their calculated age (date of testing minus date of birth). To be included in the study, participants had to be on a current baseball roster with no activity restrictions. Volunteers were excluded if they self-reported a history of nerve injury or neurologic disorder or were not cleared for full participation. Before data collection, participant assent was obtained for those under 18 years of age; informed consent was obtained for participants aged 18 years. The study was approved by the local institutional review board.

Procedures

Measurements were taken in a single session before a practice during the first half of the participant's current baseball season. Before we obtained ROM and strength measurements, participants completed a form with demographic information to ensure that they met the inclusion criteria. All measurements were completed by 2 examiners; the first examiner always performed passive ROM or applied manual resistance for the strength measures and the second examiner always took the goniometric measurements for ROM. High intrarater reliability was established for all measures (GH ROM: intraclass correlation coefficient [ICC] = 0.96 to 0.98; GH strength: ICC = 0.72 to 0.81; hip ROM: ICC = 0.93 to 0.98; hip strength: ICC = 0.81 to 0.95).

Figure 1. Glenohumeral range-of-motion positioning.

Glenohumeral internal- and external-rotation ROM measurements were taken bilaterally using a standard transparent plastic goniometer (Baseline Evaluation Instrument, Fabrication Enterprise Inc, White Plains, NY) with an attached bubble level (Figure 1). For GH passive ROM measurements, the participant was in the supine position on a portable treatment table with the hips and knees flexed. A towel was placed under the distal humerus to maintain a parallel relationship with the table to prevent excessive GH extension or horizontal abduction. While stabilizing the scapula, the examiner passively moved the participant's humerus until an end-feel was detected. A second examiner took the passive ROM measurement using a goniometer and recorded the data on paper. After ROM measurements were completed, internal- and external-rotation strength was assessed bilaterally using a MicroFet Hand-Held Dynamometer (Hoggan Health Industries Inc, Salt Lake City, UT). This instrument measures force while manual resistance is applied and fits into the examiner's hand. The participant was tested in a seated position with the shoulder at 90° of abduction. The examiner applied pressure with the dynamometer while the participant internally or externally rotated the shoulder until his form broke, similar to a muscle break test.

Hip internal- and external-rotation passive ROM was measured using a standard goniometer (Figure 2). The participant was placed in the prone position on a treatment table while the first examiner stabilized the hip with one hand and passively rotated the hip with the other hand; the second examiner recorded the measurement on paper. Hip internal- and external-rotation strength was measured with the participant in a seated position. The participant isometrically maintained a neutral position against the examiner's pressure into the internal- and external-rotation directions until the participant broke the hold, as one would with a muscle break test. Gluteus medius strength was measured with the participant lying on his side and the hip and knee flexed to approximately 90°.[13] The participant abducted and slightly externally rotated[13] the hip while resisting hip adduction against the examiner's manual pressure; a second examiner recorded the data. The TAMs for both the GH and hip joints were calculated by taking the sum of the internal- and external-rotation ROM of each.

Figure 2. Hip range-of-motion positioning.

Statistical Analyses

All ROM and strength measurements were repeated 2 times, and the average of the 2 measurements was used for analyses. Descriptive analyses (mean, standard deviation) were calculated for demographic characteristics and GH internal- and external-rotation ROM and strength, and hip internal- and external-rotation ROM and strength. A linear mixed-model approach with 3 fixed factors (age group, position, and side) and the participant as the random factor was used to determine whether differences in GH and hip ROM and strength existed. The α level was set at .05. All data were analyzed using SPSS statistical software (version 22.0; IBM Corporation, Armonk, NY).

RESULTS

Demographic characteristics of the study participants are presented in Table 1. Descriptive results of GH and hip ROM and strength are presented in Tables 2 and 3.

Glenohumeral ROM and Strength

Differences were found in GH ROM. For GH internal rotation, there were main effects for position ($F_{1,65} = 5.1$, $P = .03$) and side ($F_{1,65} = 22.446$, $P < .001$), a significant age group × side interaction ($F_{1,65} = 5.996$, $P = .02$), and a significant age group × position × side interaction ($F_{1,65} = 5.527$, $P = .02$). We observed no difference in internal-rotation ROM between sides in pitchers aged 7 to 11 years ($P = .86$); however, internal rotation was less in the throwing arm than in the non-throwing arm in position players aged 7 to 11 years ($P = .005$) and in pitchers ($P < .001$) and position players ($P < .001$) aged 12 to 18 years.

Table 2. Glenohumeral Range of Motion (°) for Throwing and Nonthrowing Arms by Age Group and Position, Mean ± SD (95% Confidence Interval)

Position	Throwing Arm			Nonthrowing Arm		
	Range of Motion			Range of Motion		
Age Group	Internal Rotation	External Rotation	Total Arc	Internal Rotation	External Rotation	Total Arc
Pitchers only						
7–11 y (n = 8)	50.0 ± 11.4 (39.5, 60.5)	105.3 ± 5.8 (98.7, 111.8)	155.3 ± 10.1 (144.2, 166.3)	49.2 ± 11.4 (41.0, 57.3)	105.1 ± 9.2 (99.3, 110.9)	154.3 ± 12.5 (144.8, 163.8)
12–18 y (n = 14)	41.1 ± 14.8 (33.1, 49.0)	99.2 ± 9.8 (94.3, 104.2)	145.0 ± 14.3 (131.9, 148.6)	57.5 ± 9.8 (51.3, 63.7)	92.4 ± 8.5 (87.9, 96.7)	149.8 ± 11.1 (142.6, 156.9)
Position players only						
7–11 y (n = 19)	52.1 ± 14.4 (45.3, 58.9)	103.5 ± 9.9 (99.2, 107.7)	155.6 ± 17.3 (148.4, 162.7)	61.2 ± 11.7 (55.9, 66.5)	99.2 ± 6.1 (95.5, 102.9)	160.4 ± 13.1 (154.3, 166.6)
12–18 y (n = 28)	44.3 ± 14.1 (45.7, 56.9)	101.4 ± 8.9 (96.3, 103.3)	145.7 ± 15.6 (145.1, 156.8)	54.5 ± 10.9 (56.4, 65.1)	97.0 ± 10.6 (91.8, 98.0)	151.4 ± 11.5 (150.4, 160.5)
All players						
7–18 y (n = 72)	48.6 ± 1.9 (44.7, 52.6)	101.9 ± 1.2 (99.5, 104.4)	150.5 ± 2.1 (146.3, 154.7)	57.2 ± 1.5 (54.1, 60.2)	97.9 ± 1.1 (95.7, 100.1)	154.9 ± 1.8 (151.4, 158.6)

Table 3. Hip Range of Motion (°) for Lead and Stance Legs by Age Group and Position, Mean ± SD (95% Confidence Interval)

Position	Leg					
	Lead			Stance		
Age Group	Internal Rotation	External Rotation	Total Arc	Internal Rotation	External Rotation	Total Arc
Pitchers only						
7–11 y (n = 8)	42.6 ± 6.4 (36.9, 48.3)	26.7 ± 8.9 (22.6, 31.1)	69.3 ± 9.2 (62.8, 75.8)	37.9 ± 4.1 (32.7, 43.0)	30.4 ± 7.1 (25.7, 35.2)	68.3 ± 9.8 (60.3, 76.3)
12–18 y (n = 14)	32.3 ± 9.2 (27.9, 36.6)	31.3 ± 5.7 (27.9, 34.7)	63.5 ± 9.2 (58.6, 68.5)	30.2 ± 5.5 (26.3, 34.2)	30.7 ± 7.7 (27.0, 34.2)	60.9 ± 9.3 (54.8, 66.9)
Position players only						
7–11 y (n = 14)	39.1 ± 7.5 (35.4, 42.8)	30.1 ± 4.8 (27.2, 32.9)	69.2 ± 9.3 (64.9, 73.4)	35.9 ± 9.1 (32.5, 39.3)	30.8 ± 5.7 (27.7, 33.8)	66.7 ± 11.8 (61.5, 71.9)
12–18 y (n = 28)	31.6 ± 8.5 (28.2, 34.3)	29.2.4 ± 6.4 (25.8, 30.6)	60.7 ± 9.3 (55.7, 62.7)	30.9 ± 6.9 (28.6, 34.1)	28.9 ± 7.0 (25.6, 30.6)	57.7 ± 11.5 (51.8, 60.4)
All players						
7–18 y (n = 72)	34.8 ± 8.8 (34.2, 38.5)	29.3 ± 6.3 (27.4, 30.7)	64.0 ± 9.9 (62.9, 67.8)	32.8 ± 7.7 (31.9, 35.8)	29.9 ± 6.8 (28.2, 31.8)	61.5 ± 12.0 (59.9, 66.0)

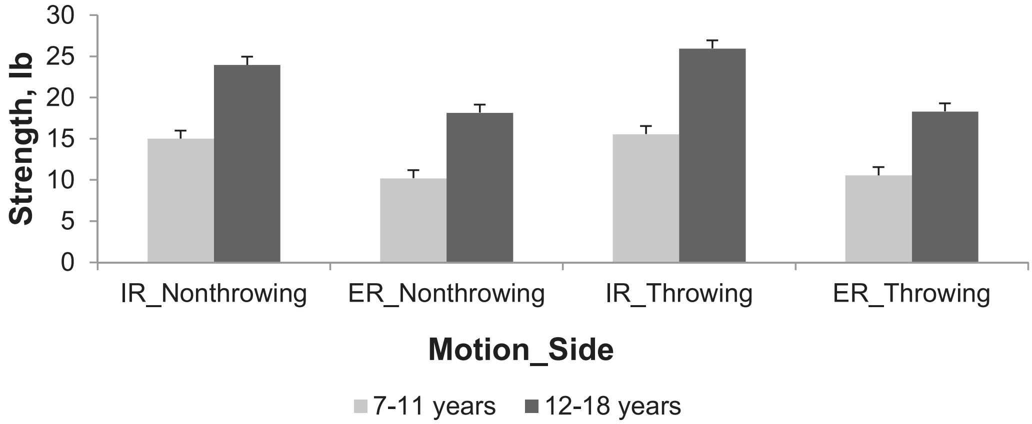

Figure 3. Glenohumeral strength measures between age groups. Abbreviations: ER, external rotation; IR, internal rotation.

For GH external rotation, there were main effects for age group ($F_{1,65} = 9.972$, $P = .002$) and side ($F_{1,65} = 16.637$, $P < .001$): the 7- to 11-year-old age group and the throwing arm had more external rotation than the 12- to 18-year-old age group and the nonthrowing arm. No other differences in GH external-rotation ROM were present (all P values $>$ .05).

For TAM at the GH joint, there were main effects for age group ($F_{1,65} = 4.367$, $P = .04$) and side ($F_{1,65} = 6.93$, $P = .01$). The TAM was greater in the 7- to 11-year-old age group than in the 12- to 18-year-old age group, and the throwing-arm TAM (150.5°) was less than that in the nonthrowing arm (154.9°).

For GH strength, main effects were noted for age group for internal rotation ($F_{1,65.354} = 49.554$, $P < .001$) and external rotation ($F_{1,65.471} = 65.913$, $P < .001$). The 12- to 18-year-old age group was stronger in internal and external rotation than the 7- to 11-year-old age group (Figure 3). A effect was also identified for side ($F_{1,64.749} = 4.108$, $P = .047$) for internal-rotation strength, such that the throwing arm was stronger in internal rotation than the nonthrowing arm.

Hip ROM and Strength

We demonstrated differences in hip ROM. Internal rotationdisplayed main effects for age group ($F_{1,65} = 17.237$, $P < .001$) and side ($F_{1,65} = 6.903$, $P = .01$). The 7- to 11-year-old age group had more internal rotation than the 12- to 18-year-old age group, and overall, the lead leg had more internal rotation than the stance leg. No hip external-rotation differences were observed between age groups, positions, or sides (all P values $>$ .05).

A main effect existed for age group ($F_{1,65} = 12.873$, $P = .001$) for hip TAM. The 7- to 11-year-old age group had a greater TAM than the 12- to 18-year-old age group.

Strength of the hip increased with age. Main effects were noted for age group for internal rotation ($F_{1,65} = 55.842$, $P < .001$), external rotation ($F_{1,65} = 34.598$, $P < .001$), and gluteus medius ($F_{1,65} = 34.562$, $P < .001$) strength. The 12- to 18-year-old age group was stronger in all directions than the 7- to 11-year-old age group (Figure 4). We identified an age × side interaction ($F_{1,65} = 4.004$, $P = .05$) for internal-rotation strength, but a post hoc test did not demonstrate any difference (P values $>$ .05).

DISCUSSION

We examined age, position, and side differences in GH and hip ROM and strength in youth baseball athletes. For GH ROM, the results for internal rotation varied between age groups, positions, and sides. Specific to age, the 7- to 11-year-old age group had more external rotation and TAM. Overall, GH internal- and external-rotation strength was greater in the 12- to 18-year-old age group and in the throwing arm. Hip internal-rotation ROM and TAM in the 7- to 11-year-old age group indicated more motion than the 12- to 18-year-old age group, but we found no differences

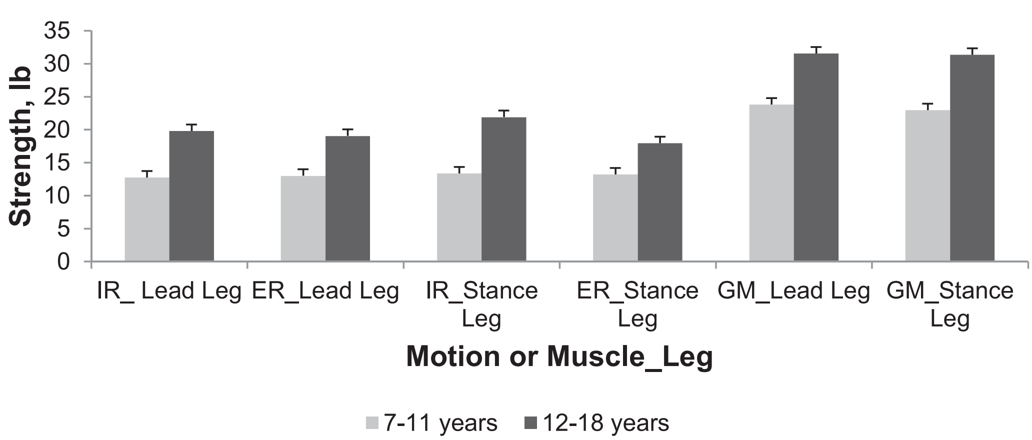

Figure 4. Hip strength measures between age groups. Abbreviations: ER, external rotation; GH, glenohumeral; IR, internal rotation.

in external-rotation ROM. Strength of the hip (internal rotation, external rotation, and gluteus medius) was greater in the 12- to 18-year-old age group. Further, the internal-rotation strength of the hip was stronger in the lead leg than in the stance leg. These results may provide additional insight about ROM and strength differences between younger and older youth baseball athletes.

Glenohumeral ROM and Strength

Differences were present in all assessed GH ROM measures, including internal rotation, external rotation, and TAM. These findings may be used to compare GH ROM in baseball athletes aged 7 to 11 years and those aged 12 to 18 years. Glenohumeral internal-rotation ROM was less in the throwing arm than in the nonthrowing arm in both age groups; however, pitchers aged 7 to 11 years had similar measurements between sides. Many athletes begin to specialize in their position at around 10 years of age,[19,20] so it is unlikely that younger athletes would have developed side-to-side changes, which may explain our ROM results in the 7- to 11-year-old age group. The 7- to 11-year-old age group had greater external-rotation ROM than the 12- to 18-year-old age group, and in both groups, the throwing arm had greater ROM than the nonthrowing arm. The TAM results were the same as the external-rotation ROM results in both groups. Although humeral retroversion may have contributed to increased motion in the GH joint in both age groups, we did not measure it because we lacked the necessary equipment. The actual increase in external rotation in the 7- to 11-year-old age group may be even higher because of the increased mobility and lack of muscle development due to developmental immaturity.

Hurd et al[21] studied GH internal- and external-rotation ROM in uninjured high school pitchers to create a ROM and strength profile that corresponds with an older youth baseball age group. Our results were similar to those found by Hurd et al[21]; specifically, the throwing arm had more external rotation and TAM than the nonthrowing arm. Although our results were statistically significant, they may not be clinically meaningful given the measurement error. Trakis et al[11] found similar results of an overall loss in internal-rotation ROM and a gain in external-rotation ROM in the throwing arm versus the nonthrowing arm when investigating injury implications. Unlike our results, Trakis et al[11] found no difference in TAM when athletes were compared bilaterally.

The presence of GH adaptations in baseball athletes at a young age seems evident. Clinically, it is important to understand "normal" ROM measures when working with baseball athletes, such as external-rotation increases and internal-rotation decreases in the throwing arm compared with the nonthrowing arm. However, TAM should be similar bilaterally in a healthy thrower. When the bilateral TAM difference is greater than 5° to 8°, the risk of injury increases.[7,22,23] The GH ROM results in our study are consistent with those of a "normal" healthy baseball athlete profile in that the throwing arm had more external-rotation and less internal-rotation ROM. When comparing TAM bilaterally, we found that the throwing arm had statistically less TAM, which suggests that these athletes may be at risk for injury. However, closer examination of our TAM data indicates about a 4° difference in the throwing arm versus the nonthrowing arm, which may not be clinically significant. Regardless, these athletes would likely benefit from an internal-rotation stretching program to minimize their injury risk.

We expected the GH strength results for our comparisons of age group, position, and side. The 12- to 18-year-old age group was stronger in GH internal and external rotation, which can be explained by their maturation level. Athletes in this age group had begun puberty and were gaining muscle mass and strength.[24] We did not find strength differences between pitchers and position players, but the throwing arm was stronger in internal rotation than the nonthrowing arm, and external-rotation strength was the same between arms. These findings are consistent with GH strength data from previous studies[25,26] of adult baseball athletes that demonstrated an increase in strength of the throwing arm compared with the nonthrowing arm. Therefore, bilateral internal-rotation strength differences seem to develop at a young age and persist through adulthood. Because internal-rotation strength is important for the acceleration phase of the throwing motion, young baseball athletes should be assessed for this side-to-side difference, and training to increase internal-rotation strength in the throwing arm should be implemented when necessary.

Glenohumeral strength is a risk factor for injury in baseball athletes.[27] As such, our goal in the current study was to determine where and when strength changes occur to find the optimal time frame for introducing an injury-prevention program for youth athletes. Our participants were healthy and had relatively normal findings compared with adult data. Therefore, these results may contribute to better awareness of normative data for young baseball athletes and of when adaptations begin to occur. The majority of our participants were not at risk for injury when measurements were taken. However, measuring these outcomes before the start of a season may allow injury-prevention programs to be put in place when needed.

Hip ROM and Strength

Hip internal rotation and TAM differed between the groups.. The 7- to 11-year-old age group had larger internal-rotation ROM and TAM than did the 12- to 18-year-old age group. These findings may be explained by increased mobility and ligamentous laxity in the younger age group because this population tends to have more elastic tissue than does the adult population.[28,29] Further, these results support the investigation of Sankar et al,[30] who found that hip internal and external rotation decreased as children aged from 2 to 17 years. Other authors[30–32] assessing normative hip ROM values also found a decline in hip ROM with increased age, which is likely caused by decreases in joint mobility and laxity and an increase in musculature with maturation. Therefore, our results suggest that our participants had average ROM for their age. However, our participants had bilateral ROM differences, which contradict the findings of Sankar et al.[30] The bilateral hip ROM differences in youth baseball athletes in our study may suggest sport-related adaptations and warrant further research.

Overall, we observed that the lead leg had more internal-rotation ROM than the stance leg but that external-rotation

ROM did not differ. During the cocking phase of the throwing motion, the lead hip and knee flex while the stance leg stabilizes. Throughout the rest of the thowing phases, the lead leg is responsible for moving the body forward, which requires more internal ROM. This finding may relate to that of Delp et al[33]: increasing hip flexion may lead to greater internal-rotation moment arms of the hip musculature. Repetitive and increased throwing volume may lead to an increase in internal-rotation ROM in the lead leg; however, this variable should be studied further to determine whether ROM adaptations are beneficial to performance or detrimental and an injury risk.

Previous studies[12,17,18] of professional baseball athletes do not support our findings about hip ROM in youth baseball athletes. For instance, Laudner et al[17] tested hip ROM in a seated position and showed that position players had greater internal-rotation ROM in their stance leg than pitchers, which can be explained by the need to prepare for positioning of the lead leg. Robb et al[18] studied hip ROM using measurements taken in a prone position and demonstrated that pitchers had less internal-rotation ROM in their lead leg than position players. However, Sauers et al[12] measured hip ROM in seated participants and found no differences in hip internal-rotation ROM between position or side; however, hip external-rotation ROM was significantly different by position (greater in position players) and side (greater in the lead leg). These contradictory results may stem from the use of different measurement techniques, such as participant positioning and instrumentation. To our knowledge, studies have been conducted only in the adult population. Our participants were healthy and aged 7 to 18 years. Normative data for hip ROM should be established in this population so that clinicians can better understand any adaptations or injury risk indicators that may exist. Our findings provide a profile of the youth and adolecent hip of baseball athletes. With this information, clinicians may be able to determine deficits and provide stretching recommendations as needed.

Lastly, as we expected, hip internal-rotation and external-rotation and gluteus medius strength increased with age. Internal-rotation strength was greater in the stance leg than in the lead leg. We noted a possible age × side interaction for internal-rotation strength, but this result was not confirmed with a post hoc analysis. These findings support the demands of the throwing motion. In the cocking phase of the throwing motion, the hip and knee flex to shift the center of gravity. In the follow-through phase, the arm decelerates and the body slows down, transferring forces to the stride foot. At that time, all posterior musculature decelerates the upper extremity until the body returns to a resting state.[34] A stronger stance leg is needed to provide a base of support for the rest of the body throughout the throwing motion. Because we demonstrated that the stance leg was stronger only in internal rotation, strengthening the external rotators and the gluteus medius may be beneficial for our participants and for those populations similar to our participants. If an athlete has deficits in hip strength during preseason screening, the deficit can be addressed before competition and before causing injury.

As for hip strength, one group[17] reported that gluteus medius strength in their stance leg was greater in position players compared with pitchers. The study suggests that each position has different movement and strength demands, and being aware of these differences can guide the practice decisions of clinicians.[17] Because pitchers were weaker in the lower extremity,[17] they may be at increased risk for injuries secondary to aquiring the energy from only part of the kinetic chain. We did not find any strength differences in position or side. However, if pitchers display weakness, strengthening is recommended to minimize injury risk.

LIMITATIONS

The current study had several limitations. Our design was cross-sectional and not longitudinal; therefore, we were unable to track each athlete over time, which could provide information on changes over time. Data collection occurred at a single time point for all participants. Thus, we were unable to gauge when these changes in ROM and strength occurred for each participant and had to compare age groups. Further, the lack of differences between pitchers and position players may reflect a lack of specialization within the 7- to 11-year-old age group: this group had significantly fewer pitchers. As a result, we cannot determine the clinical significance of the equal internal-rotation ROM results. Lastly, we measured isometric contractions. Gaining insight into concentric and eccentric strength measures could provide valuable information for a clinician. Future authors should use longitudinal methods on a larger scale to assess changes within individual athletes instead of comparing age groups and to determine in turn when and where these changes in ROM and strength occur.

CONCLUSIONS

Youth baseball athletes showed GH and hip adaptations between age groups. Glenohumeral ROM adaptations typical in baseball athletes—less internal rotation and more external rotation—were present in both age groups, indicating changes in participants as young as 8 years. Overall, ROM was greater in the 7- to 11-year-old age group. These results may be explained by less humeral retroversion, increased laxity, and less muscle mass in the 7- to 11-year-old age group compared with the 12- to 18-year-old age group. To our knowledge, we are the first to report hip ROM values in youth baseball athletes, and future investigators should establish whether decreased stance-leg hip internal-rotation ROM is clinically meaningful and related to injury. As expected, older participants were stronger than younger participants. Glenohumeral internal-rotation strength in the throwing arm is necessary to produce the high concentric forces required by the internal-rotation musculature during the acceleration phase of the overhead throw. Strength is also an important factor in completing the throwing motion. More research should be conducted to determine the general strength of non-baseball youth athletes compared with youth baseball athletes. In addition, understanding when ROM and strength adaptations present in youth and adolescent baseball athletes may allow clinicians to make more educated decisions about pitch count limitations, injury-prevention programs, and the care of injured athletes.

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Address correspondence to Kelsey J. Picha, MS, University of Kentucky, 900 South Limestone Street, Lexington, KY 40536. Address e-mail to kpicha@atsu.edu.