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Shoulder Range of Motion Measures as Risk Factors for Shoulder and Elbow Injuries in High School Softball and Baseball Players

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Investigation performed at 11 high schools in Greenville, South Carolina

Background: Range of motion deficits in shoulder external rotation (ER), internal rotation (IR), total rotation range of motion (ER + IR), and horizontal adduction (HA) have been retrospectively associated with overhand athletes' arm injuries.

Hypothesis: The authors expected the incidence of upper extremity injury in high school softball and baseball players with side-to-side shoulder range of motion deficits to be greater than the incidence of upper extremity injury in players with normal shoulder range of motion.

Study Design: Cohort study (prognosis); Level of evidence, 2.

Methods: High school softball and baseball players (N = 246) participated. Before the start of the season, passive shoulder ER, IR, and HA were assessed at 90° of abduction with the scapula stabilized. Relative risk (RR) was calculated to examine range of motion measure, by categorical criteria, and risk of upper extremity injury.

Results: Twenty-seven shoulder and elbow injuries (9 softball, 18 baseball) were observed during the season. The dominant shoulder of all injured players and baseball players displayed a significant decrease in HA ($P = .05$) and IR ($P = .04$). The dominant shoulder total rotation of injured baseball players displayed a significant decrease (mean difference = $8.0^\circ \pm 0.1^\circ$; $P = .05$) as compared with the dominant shoulder of uninjured baseball players. Players who displayed a decrease of $\geq 25^\circ$ of IR in the dominant shoulder were at 4 times greater risk of upper extremity injury compared with players with a $< 25^\circ$ decrease in IR, especially for baseball players. While we observed a 1.5 to 2 times increased risk of injury for the 10° to 20° loss in rotational range of motion for the overall sample and baseball, the risk estimates were not statistically significant ($P > .05$).

Conclusion: There are large mean deficits in shoulder IR and HA between injured and noninjured players, but not in ER or total rotation. Passive shoulder IR loss $\geq 25^\circ$ as compared bilaterally was predictive of arm injury. Shoulder range of motion deficits differed between sports and appeared more predictive of injury for baseball players.

Keywords: baseball; softball; high school; internal rotation

Shoulder and elbow injuries are common in softball and baseball at multiple competition levels.^{2,9,17,21-23} Posterior-inferior capsule and soft tissue tightness have been

suggested to alter shoulder internal rotation (IR) range of motion (ROM), often termed glenohumeral internal rotation deficit (GIRD), thereby influencing humeral head position and contributing to development of type II superior labral anterior to posterior (SLAP) lesions.^{4,6} Burkhart et al⁶ examined 44 pitchers with type II SLAP lesions. With the arm abducted at 90°, all pitchers were found to have a marked loss of IR of the shoulder with the SLAP lesion when compared with their noninjured shoulder. Grossman et al¹⁵ performed cadaveric studies to examine the effects of capsular changes suspected to occur in overhand athletes. They demonstrated that a created posterior contracture caused a decrease in shoulder IR and limited posterior-inferior translation during maximal shoulder external rotation (ER) at 90° of abduction (cocking phase of throwing), thereby forcing the humeral head to translate posterosuperiorly and load the superior labrum.¹⁵

Alterations in shoulder ROM have been suspected to increase the risk of injury among overhand athletes. While

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many authors have suggested that a reduction in shoulder IR in overhand athletes may increase their likelihood of injury,^{1,14} others have stated that a shift in shoulder rotational ROM toward reduced IR with a concomitant increase in ER is a normal occurrence in healthy throwers.⁴⁵ Currently, there is no consensus regarding the tissues responsible for this alteration in shoulder motion. Some investigators contend that soft tissue structures are responsible for the adaptations in shoulder ROM,^{5,47} while others assert that bony tissue changes cause the shift in shoulder ROM in throwers.⁸ Osseous adaptations of the humerus have been documented to result in a shift in the total arc of motion with a gain of shoulder ER that equals the loss of shoulder IR.^{8,37,51} Adaptive changes in soft tissue are thought to reflect shoulder IR deficits that exceed shoulder ER gains with a concomitant decrease in the dominant arm total rotation as compared bilaterally.⁵¹ Range of motion changes including loss of shoulder IR (range, 15°-25°) and total arc of motion have been documented in retrospective analyses of injured overhand athletes, suggesting that pain might be related to soft tissue tightness.^{27,40,47,51} Therefore, a combination of osseous and soft tissue factors may contribute to the shift in glenohumeral rotational ROM.^{25,40}

Similar patterns of altered glenohumeral rotational ROM and shoulder tightness have been reported in collegiate softball¹² and youth through adult baseball players. However, while all players are exposed to similar forces during throwing,⁵⁰ injured baseball throwers have been found to have significant reductions in dominant arm shoulder IR, total arc of motion, and horizontal adduction (HA) ROM (-19.7° IR, -8.2° total arc of motion, -4.2-cm HA) when compared with noninjured throwers (-11.1° IR, -6.0° total arc of motion, -0.9-cm HA).²⁷

Establishing a temporal link between GIRD (defined as a loss of shoulder IR [dominant compared with nondominant]), a loss of dominant arm total shoulder rotational ROM (dominant compared with nondominant), and a side-to-side loss of shoulder HA (dominant compared with nondominant) with injuries in the upper extremities of throwers is critical in understanding the association between these factors when developing screening and treatment procedures for these athletes. However, prior studies that reported a loss of shoulder ROM among injured overhand throwers have used a cross-sectional design that prevents causal determination of observed associations. Thus, the purpose of this study was to prospectively identify shoulder ROM factors that placed high school softball and baseball players at increased risk of upper extremity injury. We expected that high school softball and baseball players who displayed GIRD would have a higher incidence of upper extremity injury than players who presented with normal shoulder ROM. We also anticipated that a loss of dominant arm shoulder HA or a loss of dominant side total rotation would increase the likelihood of upper extremity injury as compared with softball and baseball players who had equal rotational and shoulder HA ROM.

MATERIALS AND METHODS

Study Population

The study prospectively examined then followed 246 high school female softball (n = 103) and male baseball (n = 143) players in 11 Greenville, South Carolina, high schools. Recruitment of a diversity of athletes from junior varsity and varsity high school teams was conducted to ensure players ranged in skill level. The teams ranged from semi-finalists in the state tournament to those who did not qualify for state competition. Several players received National Collegiate Athletic Association scholarships and 2 baseball players were drafted in the subsequent Major League Baseball draft. Players were 13 to 18 years old (mean, 15.7±1.2 years) and were classified as pitchers (n = 51) or as position players (n = 195) (Table 1). Baseball players had greater playing experience in years than softball players (*P* = .001). Athletes were excluded from the study if (1) they were being treated for a shoulder or elbow injury at the beginning of the season, (2) they were unable to participate on the first day of practice because of upper extremity injury or soreness, or (3) they had performed specific posterior capsule/sleeper stretches on the day of measurement. The coaches and athletic trainers (ATs) at each participating high school reported that they did not use a specific injury prevention stretching program before or during the season. The Rocky Mountain University of Health Professions Institutional Review Board approved the study. Parental consent and athlete assent were obtained for each participant.

Data Collection

Before the 2009 spring interscholastic season, the participants completed a study questionnaire then had their dominant and nondominant shoulder ER, IR, and HA passive ROM measured. From the beginning to the end of the season, upper extremity injuries were tracked for each participating athlete. Time-lost classifications used to assess injury severity were mild (7 or less days) and moderate/major (8 or more days lost).³⁵

Study Questionnaire. The players completed a questionnaire on baseline characteristics, including hand dominance, softball or baseball participation, and prior softball- or baseball-related injuries. Examiners were blinded to the participant's hand dominance throughout data collection.

Shoulder IR and ER Range of Motion. Shoulder IR and ER passive ROM were measured for dominant and nondominant upper extremities using a portable treatment table, or standard treatment table, and standard goniometer with a bubble level to measure shoulder ROM.^{20,25,27} Participants were placed supine and their shoulders positioned in 90° of abduction. Measurements for IR and ER were performed in the plane of abduction and a small towel roll was used to maintain the position of the humerus. A posterior force by the thenar eminence and thumb was

TABLE 1
Characteristics of High School Softball and Baseball Players^a

	Total			Softball			Baseball			P Value
	N	Mean	SD	N	Mean	SD	N	Mean	SD	
Age, y	246	15.7	1.2	103	15.6	1.2	143	15.8	1.3	.08
Experience, y	246	8.6	3.4	103	6.5	3.2	143	10.1	2.7	.001
Position, %										
Pitchers	51	20.7		12	11.7		39	27.3		.03
Catchers	25	10.2		14	13.6		11	7.7		.4
Position players	170	69.1		77	74.7		93	65.0		.2

^aSD, standard deviation.



Figure 1. Stabilization technique for range of motion measurement.

then applied through the coracoid process to stabilize the scapula before the arm was rotated,^{11,14,20,48} and the humerus was passively positioned at the end of either IR or ER ROM with the force of gravity acting on the arm.¹¹ The goniometer stationary arm was placed along the midline of the lateral forearm and the axis of the goniometer was aligned with the olecranon¹¹ (Figure 1). Two examiners performed all IR and ER measurements with 1 examiner providing stabilization force to maintain the shoulder position while the other examiner obtained the ROM measurement.³ The mean of 2 trials for was used for data analysis.

Shoulder HA Range of Motion. Shoulder HA ROM, as reported by Laudner et al,¹⁸ was measured with the athlete in the supine position on the standard table with the scapula retracted and stabilized via examiner pressure, with the thenar eminence contacting the lateral border of the scapula.^{18,29} The upper extremity was passively horizontally adducted across the body with the arm starting at 90° of abduction in neutral rotation.^{18,29} The angle between the humerus and the horizontal plane from the superior aspect of the shoulder was measured via goniometry, which has been described in the literature to be

reliable and valid.²⁹ Two measurements of HA ROM were performed and the mean calculated for each arm.

Intrarater and interrater reliability for all ROM measures were established on 10 athletes before beginning the main study. Intraclass correlation coefficients (ICCs) for intrarater and interrater measures were in the acceptable range for shoulder IR ($ICC_{(2,1)} = 0.97$; standard error of the mean [SEM] = 2.5/ $ICC_{(2,k)} = 0.97$; SEM = 2.6, 95% confidence interval [CI]: 0.95, 0.99), ER ($ICC_{(2,1)} = 0.99$; SEM = 2.0/ $ICC_{(2,k)} = 0.99$; SEM = 0.95, 95% CI: 0.98, 0.99), and HA ($ICC_{(2,1)} = 0.99$; SEM = 1.2/ $ICC_{(2,k)} = 0.98$, SEM = 1.8, 95% CI: 0.98, 0.99).

Variables for Data Analysis. Passive shoulder ER was the average of the 2 trials of ER measured. Passive shoulder IR was the average of the 2 trials for IR measured. Passive shoulder total rotation was calculated for the dominant and nondominant arm by adding the mean ER and IR for each arm, respectively. Passive shoulder HA ROM was the average of the 2 trials for HA measured. Passive shoulder IR loss was calculated by subtracting the mean dominant shoulder IR value from the mean nondominant shoulder IR value. Passive shoulder total rotation loss was calculated by subtracting the mean dominant total shoulder rotation value from the mean nondominant total shoulder rotation value. Passive shoulder HA loss was calculated by subtracting the mean dominant shoulder HA value from the mean nondominant shoulder HA value.

Injuries. Before the 2009 spring interscholastic season, participating ATs and coaches were trained in the use of the Athletic Health Care System Daily Injury Report form.^{36,39} From the first official day of practice until the last regular or postseason competition, 2 parallel recording procedures, the Simtrak mobility system (version 8, Premier Software Inc, Winfield, Illinois) and the Athletic Health Care System Daily Injury Report form,^{36,39} were used to track athlete exposures and injury incidence. An athlete-exposure (AE) was defined as 1 athlete participating in 1 practice or competition where a player was at risk of sustaining an injury.^{32-34,36,38} A baseball or softball injury was defined as any injury that occurred during any baseball or softball team-sponsored activity (from the beginning of preseason through the last postseason game) to any muscle, joint, tendon, ligament, bone, or nerve reported by the player to the coach or AT.³⁶ All

athletes who reported pain or injury to their coach were referred to the AT at their school for evaluation and classification of each injury. All injuries were categorized by injury severity (time lost categorized as mild [7 or less days] or moderate/major [8 or more days]). All upper extremity injuries regardless of onset type, gradual or immediate, were recorded.

Statistical Analysis

Means and standard deviations were calculated for each passive ROM variable for the dominant and nondominant shoulders. Independent *t* tests were used to compare dominant to nondominant mean ROM loss for all shoulder ROM variables for the overall cohort, softball, and baseball players. Independent *t* tests were used to compare mean differences in shoulder ROM deficits between the injured and noninjured groups for all ROM variables. A secondary analysis utilizing bivariate correlations was performed for shoulder ROM measures to determine the relationship between IR and HA ROM.

Upper extremity injury incidence rates were calculated for initial upper extremity and shoulder injuries, respectively, divided by the total number of AEs. Relative risk (RR) and 95% CI were calculated to compare initial upper extremity injury risks of each shoulder ROM measure, comparing the cumulative incidence in an exposed group, divided by the cumulative incidence in the baseline or referent group. Cut points, based on retrospective studies,^{4,10,26,27,40,41,47} were established for categorical risk analysis to compare side-to-side IR loss, side-to-side total rotational ROM loss, and side-to-side loss of HA in the injured and uninjured groups. The initial IR loss cut point was established at 10° based on deficits identified in comparisons of baseball players with and without a history of shoulder pain and injury.^{40,41} Similarly, the initial cut point for total rotational ROM loss of 10° was based on retrospective analysis of injured baseball players.^{10,40} Only 1 cut point, 16° side-to-side loss, has been established for HA loss.^{27,47} We used this cut point for HA loss in our risk analysis.

For all statistical analyses, an alpha level of $P < .05$ was used. All data were analyzed using SPSS for Windows (SPSS Science, Chicago, Illinois). Thus, the main power analysis was based on the power needed to detect a risk association between shoulder IR ROM and upper extremity injury. A priori, based on the incidence of upper extremity injury in our Simtrak injury surveillance system of 18 high schools the past 2 years, using a prospective cohort design, a power of 0.80, an alpha level of .05, a conservative expected estimate of 11% of noninjured players having a shoulder IR ROM greater than 20°, an expected estimate of 23% of injured players with a shoulder IR ROM greater than 20°, and an approximate RR of 2.0 or corresponding odds ratio of 2.4, an estimated sample of 300 players was determined necessary to show a statistically significant association between shoulder IR ROM and upper extremity injury. However, the preseason period was limited, and we were unable to consent, enroll, and measure the estimated 300 players prior to the first game.

RESULTS

Demographic data are presented in Table 1. Baseball players reported a greater number of years participating in their sport (10.1 ± 2.7 years) than softball players (6.5 ± 3.2 years) ($P = .001$). Twenty-seven initial shoulder (16) and elbow (11) injuries (softball $n = 9$, baseball $n = 18$) were observed during the 12-week season for an upper extremity injury rate of 2.5/1000 AEs. Pitchers sustained 12 of 27 (44.4%) of our initial upper extremity injuries. Specific upper extremity injury types by player position are listed in the Appendix (available in the online version of this article at <http://ajs.sagepub.com/supplemental/>). The shoulder injury rate was 1.5/1000 AEs and the elbow injury rate was 1.0/1000 AEs.⁴³ Most shoulder and elbow injuries (67%) were minor in nature, requiring less than 7 days of time loss (1.7/1000 AEs).⁴³ The upper extremity injury rate for our pitchers (1.1/1000 AEs) was similar to the upper extremity injury rate for our position players (1.4/1000 AEs) ($P = .57$). Three participants required shoulder surgery after the season.

For the overall study sample, the dominant arm had significantly less mean shoulder IR ($56.3^\circ \pm 12.8^\circ$ vs $63.7^\circ \pm 11.2^\circ$; $P = .001$) and HA ($31.9^\circ \pm 12^\circ$ vs $36.7^\circ \pm 13.5^\circ$; $P = .005$) than the nondominant arm. Means and standard deviations for all preseason shoulder ROM variables, by shoulder dominance and injury status, for the study sample are reported in Table 2. The dominant shoulder of all injured players was significantly lower for HA ($27.7^\circ \pm 11.6^\circ$) as compared with the uninjured players' dominant shoulder ($32.5^\circ \pm 11.9^\circ$) (mean difference = $4.8^\circ \pm 11.8^\circ$; $P = .05$). The dominant shoulder of injured baseball players was significantly lower for HA ($23.9^\circ \pm 7.8^\circ$) than the uninjured players' dominant shoulder ($31.0^\circ \pm 11.4^\circ$) (mean difference = $7.1^\circ \pm 2.8^\circ$; $P = .01$). The dominant shoulder of injured baseball players was significantly lower for total rotation ($172.1^\circ \pm 16.1^\circ$) than the uninjured players' dominant shoulder ($180.1^\circ \pm 16.2^\circ$) (mean difference = $8.0^\circ \pm 0.1^\circ$; $P = .05$). No significant differences were found for all other dominant side comparisons of the shoulder ROM variables between injured and uninjured players.

Table 3 presents the mean and standard deviations of the side-to-side ROM difference for the injured and noninjured players. For baseball players, those who were injured had a significant loss of IR between dominant and dominant shoulders ($12.1^\circ \pm 11.8^\circ$ vs $7.4^\circ \pm 8.6^\circ$, mean difference = $4.7^\circ \pm 10.2^\circ$; $P = .04$). No significant loss differences were found between injured and noninjured shoulders for HA or total rotational ROM ($P > .05$). A trend toward a significant loss of total rotation was found for baseball players who were injured compared with their uninjured counterparts between dominant and dominant shoulders ($4.6^\circ \pm 14.4^\circ$ vs $-0.52^\circ \pm 11.6^\circ$, mean difference = $5.1^\circ \pm 2.8^\circ$; $P = .09$).

For the overall cohort and baseball players, those who had a decrease in passive IR $\geq 25^\circ$ in the dominant shoulder were approximately 4 (RR = 3.7, 95% CI: 1.6, 8.9) and 5 (RR = 4.8, 95% CI: 2.1, 11.3) times at greater risk of upper extremity injury, respectively, compared with players with $< 25^\circ$ decrease in passive IR (Table 4). Three of 12 injured pitchers had a decrease of IR $\geq 25^\circ$ in the

TABLE 2
Preseason Range of Motion Data^a

Shoulder ROM Variable	Total						Softball						Baseball					
	Dominant			Nondominant			Dominant			Nondominant			Dominant			Nondominant		
	N	Mean	SD	P Value ^b	Mean	SD	N	Mean	SD	P Value ^b	Mean	SD	N	Mean	SD	P Value ^b	Mean	SD
Passive external rotation, deg	246	124.9	12.7		119.2	13.0	103	123.8	13.6		121.1	14.3	143	125.6	11.4		117.8	11.8
Injured	27	122.4	18.5	.44	117.1	19.0	9	121.8	25.1	.80	121.3	28.9	18	122.6	15.0	.25	115.1	12.0
Noninjured	219	125.2	11.8		119.4	12.1	94	124.0	12.2		121.0	12.3	125	126.1	11.5		118.2	11.7
Passive internal rotation, deg	246	56.3	12.8		63.7	11.2	103	60.2	13.6		66.8	12.1	143	53.4	11.4		61.4	9.9
Injured	27	56.7	19.7	.85	66.7	16.5	9	71.3	25.9	.20	76.8	24.3	18	49.5	10.4	.12	61.6	7.6
Noninjured	219	56.2	11.8		63.3	10.3	94	59.2	11.5		65.8	9.9	125	54.0	11.5		61.4	10.3
Passive total rotation, deg	246	181.2	17.8		182.8	17.2	103	184.1	19.3		187.9	19.0	143	179.1	16.4		179.2	14.8
Injured	27	179.1	23.1	.60	183.8	23.8	9	193.1	29.4	.14	198.1	35.5	18	172.1	16.1	.05	176.7	10.5
Noninjured	219	181.4	17.0		182.7	16.3	94	183.2	18.0		186.8	16.7	125	180.1	16.2		179.6	15.3
Passive horizontal adduction, deg	246	31.9	12.0		36.7	13.5	103	34.4	12.5		41.5	14.0	143	30.1	11.2		33.2	11.9
Injured	27	27.7	11.6	.05	31.0	10.4	9	35.3	14.4	.84	36.6	14.2	18	23.9	7.8	.01	28.3	6.8
Noninjured	219	32.5	11.9		37.4	13.6	94	34.4	12.3		42.0	14.0	125	31.0	11.4		33.9	12.4

^aROM, range of motion; SD, standard deviation.

^bIndependent *t* test.

TABLE 3
Dominant and Nondominant Range of Motion Comparison^a

	Total							Softball							Baseball						
	Injured			Noninjured				Injured			Noninjured				Injured			Noninjured			
	N	Mean	SD	N	Mean	SD	P Value ^d	N	Mean	SD	N	Mean	SD	P Value ^d	N	Mean	SD	N	Mean	SD	P Value ^d
Passive internal rotation loss, deg ^b	27	9.9	11.2	219	7.1	8.8	.12	9	5.5	8.7	94	6.6	9.0	.72	18	12.1	11.8	125	7.4	8.6	.04
Passive total rotation loss, deg ^c	27	4.7	13.6	219	1.3	11.8	.16	9	4.9	12.5	94	3.7	11.7	.75	18	4.6	14.4	125	-0.52	11.6	.09

^aSD, standard deviation.

^bPassive internal rotation loss = the difference between the mean dominant shoulder internal rotation value and the mean nondominant shoulder internal rotation value.

^cPassive total rotation loss = the difference between the mean dominant shoulder total rotation value and the mean nondominant shoulder total rotation value.

^dIndependent *t* test.

dominant shoulder on side-to-side comparison. These injured pitchers had a 10-times (RR = 9.7, 95% CI: 1.1, 85.3) greater risk of upper extremity injury compared with pitchers with <25° decrease in passive IR. None of the 3 softball players who had a decrease of IR ≥25° in the dominant shoulder had an upper extremity injury. Risk comparisons for ≥10°, ≥15°, and ≥20° passive IR criteria were not statistically significant (*P* > .05). While the risk of upper extremity was 2 (RR =2.3, 95% CI: 0.9, 6.0; *P* = .10) and 3 (RR = 3.0, 95% CI: 1.1, 8.4; *P* = .08) times greater with a loss in passive total arc of motion of >20° for the overall sample and baseball, respectively, only trends were observed (Table 4). Loss of dominant HA was not significantly associated with injury risk at any criterion level for the overall sample, baseball, or softball players (*P* > .05).

Bivariate correlations between passive IR and HA ROM measures were performed as a secondary analysis. Mean dominant passive IR was positively correlated with dominant HA among the baseball players (*r* = .44, *P* < .001), softball players (*r* = .39, *P* < .001), and overall sample (*r* = .43, *P* < .001). Mean dominant passive IR was not

significantly correlated with side-to-side loss of HA in our baseball players, softball players, and overall cohort. Mean dominant HA was negatively correlated with a loss of passive IR (nondominant – dominant) in the overall sample (*r* = -.21, *P* = .001), in baseball players (*r* = -.34, *P* < .001), and in softball players (*r* = -.029, *P* = .009). Mean loss of side-to-side passive IR was not significantly correlated with mean side-to-side loss of HA.

DISCUSSION

Main Findings

The results of our study indicated that players who displayed a preseason decrease in passive IR ≥25° in the dominant shoulder as compared bilaterally were at 4 to 5 times greater risk of an upper extremity injury than players with <25° decrease in passive IR. Injured baseball players also had a significant side-to-side loss of passive IR (mean difference = 4.7°) in comparison with the uninjured

TABLE 4
Internal and Total Rotation ROM Risk Factors for Initial Injury for Softball and Baseball Players
Who Competed During the 2009 Season in Greenville, South Carolina^a

	Total				Softball				Baseball			
	No. at Risk	% Injured	RR	95% CI	No. at Risk	% Injured	RR	95% CI	No. at Risk	% Injured	RR	95% CI
Passive IR ROM side-to-side difference												
<10°	155	9.0	1.0		68	8.8	1.0		87	9.2	1.0	
≥10°	91	14.3	1.6	0.8, 3.2	35	8.6	0.97	0.3, 3.7	56	17.9	1.9	0.8, 4.6
<15°	199	9.5	1.0		87	8.0	1.0		112	10.7	1.0	
≥15°	47	17.0	1.8	0.8, 3.8	16	12.5	1.6	0.4, 6.8	31	19.4	1.8	0.7, 4.4
<20°	221	10.4	1.0		96	9.4	1.0		125	11.2	1.0	
≥20°	25	16.0	1.5	0.6, 4.1	7	0.0	0.0	NA	18	22.2	2.0	0.7, 5.4
<25°	235	9.8	1.0		100	9.0	1.0		135	10.4	1.0	
≥25°	11	36.4	3.7	1.6, 8.9	3	0.0	0.0	NA	8	50.0	4.8	2.1, 11.3
Passive total ROM side-to-side difference												
<10°	185	9.2	1.0		74	8.1	1.0		111	9.9	1.0	
≥10°	61	16.4	1.8	0.9, 3.7	29	10.3	1.3	0.3, 4.8	32	21.9	2.2	0.9, 5.2
<15°	210	10.5	1.0		85	9.4	1.0		125	11.2	1.0	
≥15°	36	13.9	1.3	0.5, 3.3	18	5.6	0.60	0.7, 4.4	18	22.2	2.0	0.7, 5.3
<20°	229	10.0	1.0		95	8.4	1.0		134	11.2	1.0	
≥20°	17	23.5	2.3	0.9, 6.0	8	12.5	1.5	0.2, 10.4	9	33.3	3.0	1.1, 8.4
<25°	239	10.5	1.0		99	8.1	1.0		140	12.1	1.0	
≥25°	7	28.6	2.7	0.8, 9.3	4	25.0	3.1	0.5, 19.1	3	33.3	2.7	0.5, 14.1

^aROM, range of motion; RR, relative risk; CI, confidence interval; IR, internal rotation; No. at risk, total number of players at risk in category; % injured, percentage of players in category with injury; NA, not applicable.

baseball players. Overall, the increased risk for players who presented with less dominant shoulder IR (as compared bilaterally) was independent of a loss of total arc of motion. A dominant loss of shoulder HA was not associated with injury risk at any criterion point. However, injured players did display less shoulder HA of the dominant arm as compared with the uninjured group's dominant arm (mean difference = 4.8°), which appears primarily attributable to injured baseball players because they had 7.1° less in passive shoulder HA as compared with the non-injured baseball players. Additionally, the dominant shoulder of softball players demonstrated significantly greater rotational (IR + ER) ROM and HA than the dominant arm of baseball players.

Injuries

During the 12-week season, we found that the overall rates for upper extremity injury were relatively low for interscholastic softball and baseball, which is consistent with prior studies that reported low rates of injury for both softball and baseball players.^{16,38} While the shoulder was the most frequently injured body location, followed by the elbow, for the overall sample, the rates of injury at these body locations differed by sport. The shoulder has been identified among the most commonly injured body locations in high school softball and baseball athletes.^{2,17,32} In our sample (246 players with 27 upper extremity injuries—16 shoulders and 11 elbows), we found that softball and baseball players were more likely to sustain a shoulder injury during the first month of the season

than the subsequent 2 months during the season. In our study, elbow injuries were sustained more frequently in baseball than softball. Elbow injuries were not reported as a specific body location reported by other authors so it is difficult to compare these results.^{7,17,38} Contrary to the reports of Powell and Barber-Foss,^{32,33} no forearm, wrist, or hand injuries were incurred among our sample of softball or baseball players.

Injury by Mean Shoulder ROM Values

In our prospective study, injured baseball players had a significant mean loss of passive shoulder IR (nondominant vs dominant) when compared with uninjured players. This finding is consistent with retrospective studies analyzing the athletes' shoulder ROM when they presented with pain.^{4,5,10,27,41,47} At the start of the season, the mean shoulder IR loss of our injured baseball players was 12.1° ± 11.8° before the development of shoulder/arm pain. This difference compares favorably with shoulder IR loss reported in injured professional pitchers (10.1° ± 9.0°) and position players (13.5° ± 8.8°)⁴¹ and a cohort of collegiate baseball players of whom those reporting pain had lost 13.7° of IR on their dominant side.⁴⁰ In contrast to our findings, Myers et al²⁷ found a loss of 19.7° ± 12.8° of shoulder IR (involved compared with uninvolved) in a sample of 11 collegiate athletes with internal impingement compared with a loss of IR of 11.1° ± 9.4° in matched controls. Forty-four baseball pitchers with type II SLAP lesions were found to have a loss of shoulder IR of 25° or more, which was defined by the authors as GIRD.⁶ The

differences between their findings and ours might be attributed to the fact that our athletes were younger and were measured before their injury occurrence.

In our cohort, injured throwers' average shoulder total arc of motion was 4.7° less when compared with uninjured baseball players. This mean loss of motion in injured players is less than the mean loss of 9.6° found by Ruotolo et al⁴⁰ and 9.7° by Dines et al.¹⁰ The differences in findings may be related to the ages of the different samples (15.7-year-old softball and baseball players vs 19.5- and 21.1-year-old baseball players) and time when measures were assessed (participants in our study were uninjured when measured whereas the other studies measured their athletes after the development of mild to severe injuries). The discrepancies in results may also be related to the different measurement methods, especially stabilization techniques. Retrospective studies have measured shoulder ER and IR ROM for injured athletes in the supine position,¹⁰ while others have measured athletes with pain in the seated position⁴⁰ with less documented stabilization at the glenohumeral joint than our study (a posterior force was applied through the coracoid process to stabilize the scapula while the patient was positioned in supine with the arm position at 90° of abduction before the arm was rotated).

Shoulder HA loss attributed to capsular and rotator cuff involvement has been postulated to limit humeral head translation during the throwing motion and contribute to the development of injury.²⁴ In our study, injured players displayed a mean loss of dominant shoulder HA of 5.2° when compared with the uninjured players' dominant shoulder HA. Myers et al²⁷ reported that throwers with pathologic internal impingement had a loss of 4.2 cm in shoulder HA during side-to-side measurement. Tyler et al⁴⁷ also reported similar decreases in shoulder HA among patients with subacromial impingement.

Myers et al²⁹ measured shoulder HA ROM in both side-lying and supine positions and compared the difference in centimeters from side-lying to the degree differences measured in supine. For comparative purposes, we calculated that a 2-cm difference equated to an approximate 8° motion loss.²⁹ A 4-cm side-to-side shoulder HA loss has been documented in the injured shoulders of adults presenting with subacromial impingement⁴⁷ and collegiate baseball players with internal impingement.²⁷ This 4-cm loss (16°) was much greater than the approximate 5° loss found in our injured throwers. The smaller side-to-side differences in our study may be attributable to the difference in sample demographics between the studies (younger athletes with decreased skeletal maturity, differences in gender, and experience level) and that our athletes were measured before injury rather than measuring the shoulder HA after the players had reported shoulder pain.

We were surprised that the loss of HA in the dominant shoulder as compared with the contralateral shoulder was not associated with an increased risk of injury. While our results (positive correlation for dominant IR and HA) are in agreement with the correlations published by Laudner et al,¹⁸ the lack of correlation between side-to-side loss of shoulder HA with the loss of passive shoulder IR in

bilateral comparison may be related to the potential confounding effects of humeral torsion given that some of our softball and baseball players had likely not reached skeletal maturity.

Injury by Risk Criteria

To our knowledge, this is the first longitudinal study to report the risk of upper extremity injury based on shoulder ROM data measured before the development of injury among high school softball and baseball players. Our data suggest that high school players, especially baseball players, with a dominant arm shoulder IR $\geq 25^\circ$ had a higher incidence of upper extremity injury as compared with softball and baseball players who demonstrated $< 25^\circ$ of dominant arm shoulder IR. This finding is consistent with the retrospective data measures presented by Burkhart et al,⁴ Tyler et al,⁴⁷ and Myers et al.²⁷ Interestingly, the 25° criterion is similar to the description by Burkhart et al⁴ of GIRD. We also observed increased risks of injury for the overall sample and baseball players who lost $> 20^\circ$ and $\geq 25^\circ$ of shoulder total arc of motion, but the risk estimates were not statistically significant. This may be partially attributable to the low number of participants who incurred an upper extremity injury in our study.

Myers et al²⁸ reported that shoulder HA had a stronger correlation with humeral torsion than shoulder IR or ER ROM measures. The authors hypothesized that the amount of humeral torsion might alter the orientation of the posterior rotator cuff fibers and shoulder capsule and therefore might influence the HA measurement.²⁸ They concluded that the shoulder HA measure may not be appropriate to compare tightness between individuals.²⁸ Several studies have documented a significant difference in humeral retroversion between the dominant and nondominant shoulder in overhand athletes.^{8,28,31,37} The side-to-side comparison of shoulder HA in our study was not associated with injury in softball and baseball players, which may be attributable to the potential confounding effect of humeral torsion, which was not measured in our study. Shoulder HA requires further exploration in a spectrum of uninjured and injured athletes, along with other shoulder ROM measures and humeral torsion, to quantify skeletal maturity to determine its importance.

Normative Data

While motion differences between dominant and nondominant shoulders of Little League and adult baseball players are well documented,[#] we are unaware of any reports of normative shoulder ROM data for all adolescent high school-aged players. The differences found between the dominant and nondominant shoulders of throwers in our study are consistent with other baseball preseason

[#]References 14, 19, 25, 30, 42, 45, 48, 51.

studies.^{13,45} We did not observe the same trend for progressive side-to-side differences as baseball players aged (increasing dominant passive ER and decreasing dominant passive IR).¹⁹ The equivocal findings between our study and other published data may be explained by sample size, variation in participant age, and differences in measurement techniques, including stabilization provided, and equipment used for measurements.

Comparisons of shoulder ROM measures reported for softball players are difficult as there is a paucity of available research. While the shoulder ROM patterns found in our study are similar to studies of collegiate softball players,^{12,49} to our knowledge, norms for shoulder ROM in high school softball players have yet to be published. Dover et al¹² established baseline measures of active shoulder IR and ER measured supine in collegiate softball players. Similar to our findings, they found differences in shoulder IR and ER between the dominant and nondominant extremities.¹² The absolute mean measures revealed a very small difference for active ER (4° difference) but a much larger difference for active IR (40.1° difference).¹² Youth softball players (n = 23) demonstrated mean dominant passive shoulder ER of 129° and IR of 57°, which was similar to our findings.⁴⁹ Another study examined pre- and postseason shoulder ROM in healthy collegiate female tennis, volleyball, and swimming athletes.⁴⁴ While our passive shoulder IR measures were comparable with their tennis athletes' preseason values only, the passive shoulder ER and total arc of motion of our younger high school softball athletes was greater than the shoulder ER and total arc of motion values for their entire cohort.⁴⁴ In summary, the differences between the shoulder ROM data found in the literature and our sample may be explained by the athletes' age, sports participation type, and differences in measurement methodology, including differences in stabilization and use of overpressure to establish end range of available shoulder ROM.

Strengths

The study's prospective design established a summary of the shoulder ROM factors before participation and the development of injury, decreasing the amount of measurement bias. Recall bias and misclassification of injuries were minimized as trained health care professionals collected the data in a controlled, systematic, and prospective manner. We contacted coaches and ATs on a weekly basis, and data were collected with parallel systems to increase the accuracy of our injury data. The study was conducted over a relatively small geographical area, which allowed us to control factors related to exposure (climate and competition level) and documentation of injury circumstances. The injury data were homogeneous with respect to the number of injuries documented in the Simtrak system for the previous 2 years. Finally, the inclusion of high school softball and baseball players represents a different sample than documented in the current literature, helping to extend the understanding of shoulder ROM and injury factors as overhand athletes mature and develop.

Potential Study Limitations

The relatively low incidence of upper extremity injuries in these sports and small sample size likely limited our findings, especially for softball players. The limited number of injuries also might have been affected by the short duration of the high school season (12 weeks). The relationship between the magnitude of injury and amount of motion loss is unclear in the literature. The injuries in our study were largely mild in nature, requiring less than 8 days of time loss for recovery, and therefore our ROM risk results might be limited to less severe injuries. Additionally, the characteristics of our high school softball and baseball teams may differ from those in other geographical regions, limiting the generalizability of the findings. Documentation of skeletal maturity would aid in providing more precise descriptions of motion limitation; we did not measure this, but it should be included in future studies. Humeral retrotorsion may have influenced these measures and should be measured in future studies. The definition of GIRD is variable in the literature and based on this lack of consistency we chose to compare the side-to-side difference for each ROM variable as an independent injury risk factor. A detailed comparison to the various definitions of GIRD was beyond the scope of this article but should be considered in future studies.

Recommendations

Based on our findings and prior reports,^{4,20,46} we recommend that high school softball and baseball players with a $\geq 25^\circ$ difference in side-to-side shoulder IR during preseason testing might consider enrolling in a prophylactic stretching program, especially for baseball players. However, it is important to consider the potential effects of bony changes on this measure. Thus, we would recommend that humeral torsion or IR loss with respect to the total arc of motion deficit be accounted for or considered before instituting a stretching program. It is important to recognize high school softball and baseball players present differently in terms of shoulder ER, IR, HA, and total arc of motion but their trends for side-to-side differences are similar. We recommend continued study in this population of athletes with a larger sample incorporating sequential measures to quantify the risk of injury over time.

Conclusion

Shoulder ROM that was predictive of injury for the total cohort was a loss of $\geq 25^\circ$ of IR during side-to-side comparison. Range of motion alterations for total rotation and IR differed between softball and baseball players and these ROM deficits appeared more predictive of injury for baseball than softball players. High school softball and baseball players had large mean deficits in shoulder IR and HA as compared with their nondominant arm. Softball players demonstrated significantly greater rotational ROM and HA than baseball players in a comparison of dominant shoulder ROM between groups. Larger studies are needed

that include serial ROM, osseous humeral morphologic characteristics, and physical maturity data to quantify the risk for injury to which high school softball and baseball players may be exposed.

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