Journal of Athletic Training 2010;45(1):44–50

www.nata.org/jat

Internal Rotation and Scapular Position Differences: A Comparison of Collegiate and High School Baseball Players

Stephen J. Thomas, MEd, ATC*; Kathleen A. Swanik, PhD, ATC†; Charles B. Swanik, PhD, ATC*; John D. Kelly IV, MD‡

*University of Delaware, Newark, DE; †Neumann College, Aston, PA; ‡University of Pennsylvania Hospital, Philadelphia, PA. Mr Thomas is now at McKay Orthopaedic Research Laboratory, University of Pennsylvania, Philadelphia, PA.

Context: Conditions such as labral and rotator cuff injuries have been linked with decreases in glenohumeral internal-rotation and increases in external-rotation motion. Also, decreased glenohumeral internal rotation is strongly associated with scapular dyskinesis.

Objective: To compare healthy collegiate and high school baseball players' glenohumeral joint range of motion and scapular position.

Design: Cross-sectional study.

Setting: Institutional research laboratory.

Patients or Other Participants: Thirty-one male National Collegiate Athletic Association Division I collegiate (age = 20.23 ± 1.17 years, height = 186.24 ± 5.73 cm, mass = 92.01 ± 7.68 kg) and 21 male high school baseball players (age = 16.57 ± 0.76 years, height = 180.58 ± 6.01 cm, mass = 79.09 ± 11.51 kg).

Main Outcome Measure(s): Glenohumeral internal and external rotation and scapular upward rotation were measured with a digital inclinometer. Scapular protraction was measured with a vernier caliper. All variables except scapular upward rotation were calculated as the difference between the dominant and nondominant sides.

Results: Collegiate baseball players had more glenohumeral internal-rotation deficit (4.80°, $P = .028$) and total motion deficit (5.73°, $P = .009$) and less glenohumeral external-rotation gain (3.00°, $P = .028$) than high school players. Collegiate baseball players had less scapular upward rotation than high school players at the 90° (4.12°, $P = .015$, versus 3.00°, $P = .025$) and 120° (4.00°, $P = .007$, versus 3.40°, $P = .005$) positions. The scapular protraction difference was greater in collegiate baseball players than in high school players in the hands-on-hips and 90° positions (0.77 cm, $P = .021$, and 1.4 cm, $P = .001$).

Conclusions: When comparing high school with collegiate baseball players, these data suggest that glenohumeral internal-rotation deficit and scapular position change as the level of competition increases.

Key Words: glenohumeral joint, glenohumeral internal-rotation deficit, scapular dyskinesis

Key Points

- Compared with high school baseball players, Division I collegiate baseball players demonstrated greater glenohumeral internal-rotation deficit, total motion deficit, and scapular protraction and less glenohumeral external-rotation gain and scapular upward rotation.
- As the level of competition increases, glenohumeral internal-rotation deficits and scapular alterations worsen, a pattern also seen in athletes with shoulder injuries.
- Minimizing glenohumeral internal-rotation deficits in high school baseball players may prevent scapular malposition and its associated negative consequences.

Asymmetric passive shoulder range of motion,[1–4] coupled with scapular dyskinesis,[5–7] has been documented in throwing athletes and may be a predisposing factor to injury.[8–10] However, the order and nature of these physiologic mechanisms, for both glenohumeral and scapular changes, remain controversial. Many[2,4,11–13] believe that increased external rotation is the primary event in the progression of shoulder injuries and results from repetitive microtraumatic stretching of the anterior capsule in throwers. Others[9,10,14–17] have suggested that glenohumeral internal-rotation deficits (GIRD) are the principal adaptation leading to injury. Finally, it has also been suggested[18] that total motion should be examined in these individuals to minimize the risk for shoulder injuries.

Scapular dyskinesis is defined as an observable alteration in the position and motion of the scapula relative to the thoracic cage.[19,20] Alterations that have been identified in baseball players include increased protraction, anterior tilting, and decreased upward rotation.[5–7,21] These changes in motion are thought to be detrimental to normal functioning of the shoulder complex, ultimately placing increased stress on the static and dynamic restraints of the shoulder.[5–7,20,21] Although scapular dyskinetic patterns have been described in association with GIRD[6,10] and anterior capsular elongation,[20] the nature of this association has not been elucidated. Nonetheless, increased exposure to throwing and greater intensity of competition may potentiate these alterations and contribute to an increased risk of injury.[4,6,12,22]

The purpose of our study was to compare GIRD and glenohumeral external-rotation gain (ERG), in conjunction with scapular positioning differences in collegiate and high school baseball players, to determine whether the level of competition has an effect on these alterations. Our hypothesis was that collegiate baseball players would have greater GIRD, ERG, total motion deficit (TMD), and scapular protraction difference (calculated as dominant side – nondominant side) and less scapular upward rotation than high school baseball players.

METHODS

Research Design

We used a cross-sectional, mixed-model design to assess 5 dependent variables and 1 independent variable. The independent variable was level of competition (college and high school). All dependent variables were calculated as the difference between the dominant and nondominant sides. The dependent variables were scapular upward rotation difference (rest, 60°, 90°, and 120° of glenohumeral abduction), scapular protraction difference (rest, hand on hips, and 90° of glenohumeral abduction), GIRD, ERG, and TMD. All measurements were taken at 1 preseason time point.

Participants

Thirty-one male National Collegiate Athletic Association Division I collegiate baseball players (13 pitchers, 18 position players [age = 20.23 ± 1.17 years, height = 186.24 ± 5.73 cm, mass = 92.01 ± 7.68 kg]) and 21 male high school baseball players (7 pitchers, 14 position players [age = 16.57 ± 0.76 years, height = 180.58 ± 6.01 cm, mass = 79.09 ± 11.51 kg]) volunteered to participate in this study. Exclusion criteria consisted of a current shoulder or elbow injury. The study was approved by the university's institutional review board. Informed consent was obtained from the participants or from the participants' parents for those younger than 18 years. Health History Questionnaire and Health Insurance Portability and Accountability Act forms were completed before testing.

Instrumentation

Glenohumeral internal and external rotation were measured using a Saunders digital inclinometer (The Saunders Group Inc, Chaska, MN). A priori test-retest reliability of glenohumeral range of motion was assessed by the primary investigator (S.J.T.). Twenty healthy shoulders were measured and then remeasured 3 to 5 days later. The intraclass correlation coefficient (ICC 2,1) and standard error of measurement values for glenohumeral range of motion were 0.989 and 1.03° and 0.943 and 2.55° for internal and external rotation, respectively.[23]

Scapular upward rotation was measured using the digital inclinometer, which was modified to rest evenly on the scapular spine (Figure 1). Measurements were taken at rest and at 60°, 90°, and 120° of abduction. The digital inclinometer was modified using methods described by Johnson et al.[24] A priori test-retest reliability of the scapular upward rotation measurements was assessed by the primary investigator (S.J.T.). Thirty-six healthy shoulders were measured and then remeasured 3 to 5 days later. The ICC (2,1) and standard error of measurement values for scapular upward rotation were 0.967 and 0.70°, 0.946 and 1.55°, 0.974 and 0.86°, and 0.965 and 0.89° at rest and at 60°, 90°, and 120° of glenohumeral abduction, respectively.[23]

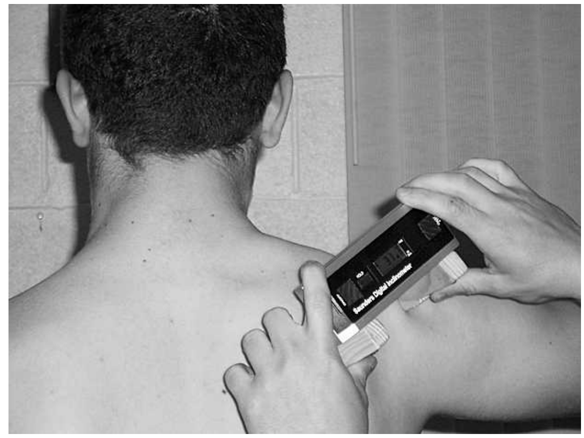

Figure 1. Measurement of scapular upward rotation using a modified digital inclinometer. Reprinted with kind permission of Springer Science and Business Media from Thomas SJ, Swanik KA, Swanik CB, Kelly JD IV. Internal rotation deficits affect scapular positioning in baseball players [published online ahead of print October 20, 2009]. ***Clin Orthop Rel Res.*** **doi:10.1007/s11999-009-1124-z.**

Scapular protraction was measured using the Kibler lateral scapular slide test[19] with a vernier caliper (model 505-633-50; Mitutoyo UK Ltd, Hampshire, United Kingdom; Figure 2) recorded in centimeters. A priori test-retest reliability of the scapular protraction measurements was assessed by the primary investigator (S.J.T.). Thirty-six healthy shoulders were measured and then remeasured 3 to 5 days later. The ICC and standard error of measurement values for scapular protraction were 0.935 and 0.328 cm, 0.970 and 0.186 cm, and 0.975 and 0.231 cm at rest, hands on hips, and 90° of glenohumeral abduction, respectively.[23]

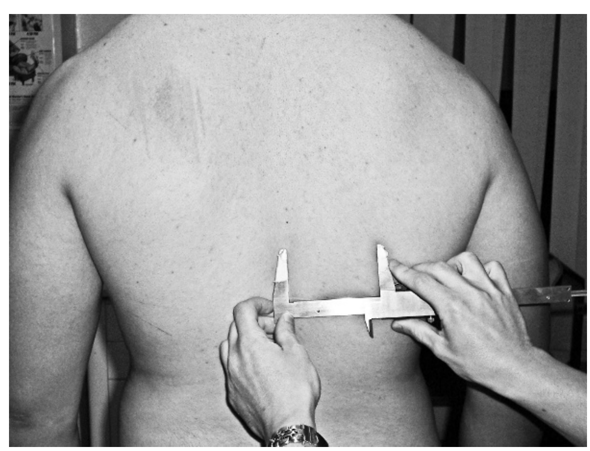

Figure 2. Measurement of scapular protraction using vernier caliper. Reprinted with kind permission of Springer Science and Business Media from Thomas SJ, Swanik KA, Swanik CB, Kelly JD IV. Internal rotation deficits affect scapular positioning in baseball players [published online ahead of print October 20, 2009]. ***Clin Orthop Rel Res.*** **doi:10.1007/s11999-009-1124-z.**

Procedures

Passive internal and external rotation measurements were taken in the supine position, with the glenohumeral joint in 90° of abduction. The scapula was then stabilized by the tester's hand, and the arm was rotated until scapular motion was detected.[25] The inclinometer was placed on the dorsal surface of the forearm, and the hold button was pressed to record the measurement. This procedure was repeated 3 times, and the average of the 3 measurements was used. All measurements were taken bilaterally by the primary investigator (S.J.T.), who was blinded to the arm dominance of the athlete, and the order of testing was alternated.

Scapular upward rotation measurements were taken with the participant standing in normal, relaxed posture. A guide pole was used to help position the participant's arm at the 60°, 90°, and 120° of abduction positions. When the appropriate amount of abduction was achieved, a pin was inserted into the guide pole. The volunteer was asked to abduct the arm until it was positioned against the pin and hold this position until the measurement was recorded. The lateral arm of the inclinometer was then placed over the posterior-lateral acromion, and the medial arm was placed over the root of the scapular spine. The hold button was pressed to record the measurement. This procedure was repeated twice, and the average of the 2 measurements was used. All measurements were taken bilaterally by the primary investigator (S.J.T.).

Scapular protraction measurements were taken with the participant standing with normal, relaxed posture. The measurements were performed at 3 different positions (rest, hands on hips, and 90° of glenohumeral abduction with maximum internal rotation). First, the inferior angle of the scapula was palpated, and the lateral arm of the caliper was placed at the tip of the inferior angle. The medial arm of the caliper was then positioned at the corresponding spinous process, and the measurement was recorded. This procedure was repeated 3 times, and the average of the measurements was used for analysis.

Data Analysis

Data analysis consisted of interferential and descriptive statistics. Separate 2-way multivariate analyses of variance were performed for the difference in scapular upward rotation and protraction. Follow-up, 2-way multivariate analyses of variance were performed on dominant-side and nondominant-side scapular upward rotation. Separate, 2-way analyses of variance were performed for GIRD, ERG, and TMD ($\alpha \leq .05$). We used SPSS (version 13.0; SPSS Inc, Chicago, IL) for data analysis.

RESULTS

Means and SDs for GIRD, ERG, and TMD are presented in Table 1. Overall, high school players had less GIRD ($P = .028$; Figure 3), greater ERG ($P = .028$; Figure 4), and less TMD ($P = .009$; Figure 5) than collegiate baseball players. Means and SDs for scapular upward rotation difference are presented in Table 2. Main effects were found for level of competition ($P = .005$). Follow-up analyses of variance revealed that scapular upward rotation difference at the rest position was less for high school than for collegiate players ($P = .0001$). Because scapular upward rotation was not different between groups, the dominant and nondominant sides were examined separately. Overall, high school players had greater scapular upward rotation on the dominant side at the 90° ($P = .015$) and 120° positions ($P = .025$) than collegiate baseball players (Table 3). High school players also had greater scapular upward rotation on the nondominant side at the 90° ($P = .007$) and 120° positions ($P = .005$) than collegiate players (Table 3). Main effects for scapular protraction difference were found between levels of competition ($P = .029$), and follow-up analyses of variance revealed that scapular protraction differences at the hands-on-hips ($P = .021$) and 90° ($P = .001$) positions were less for high school than for collegiate baseball players (Table 4).

Table 1. Glenohumeral Range of Motion in Collegiate and High School Baseball Players, Mean ± SD, °

Glenohumeral Range of Motion	Baseball Players	
	Collegiate	High School
Internal-rotation deficit	17.04 ± 8.6	12.24 ± 5.34[a]
External-rotation gain	2.33 ± 4.46	4.93 ± 2.73
Total motion deficit	13.78 ± 8.72	8.05 ± 5.20

[a] Difference between collegiate and high school players ($P < .05$).

DISCUSSION

We identified less GIRD, TMD, and scapular protraction difference in high school baseball players than in collegiate baseball players. High school baseball players had more ERG and scapular upward rotation than collegiate baseball players. Increased GIRD, ERG and scapular protraction have been commonly observed in athletes with shoulder conditions.[5,6,26]

Glenohumeral Internal-Rotation Deficit

Glenohumeral stability is maintained during overhead throwing by the continual effort of the passive and active restraints. The ligaments and capsule provide passive support, while the surrounding muscles optimize dynamic

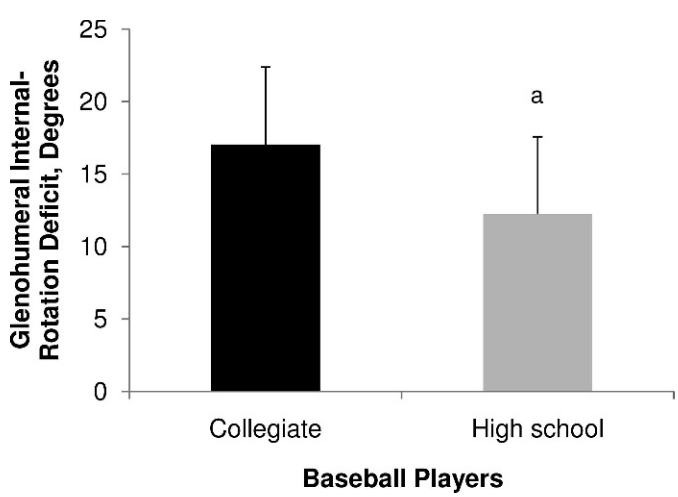

Figure 3. Glenohumeral internal-rotation deficits in collegiate versus high school baseball players. [a] Difference between collegiate and high school players was significant ($P < .05$).

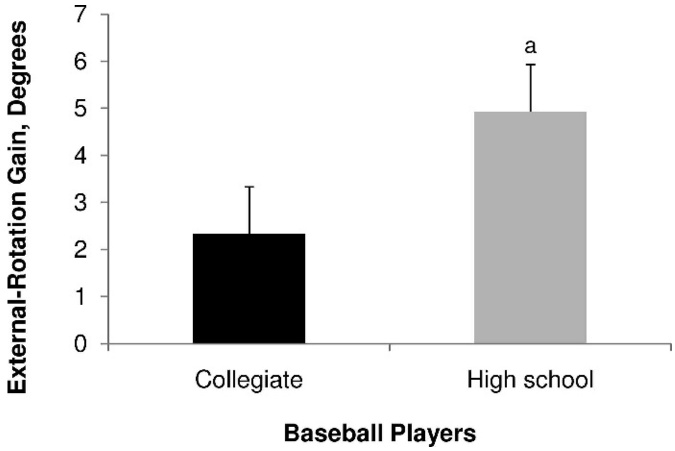

Figure 4. Glenohumeral external-rotation gains in collegiate versus high school baseball players. [a] Difference between collegiate and high school players was significant ($P < .05$).

stability by steering and compressing the humeral head in the glenoid fossa.[11,27–29] The rotator cuff muscles concentrically contract to accelerate the arm forward and also eccentrically lengthen to decelerate the humerus during overhead throwing.[11,30] The clinical presentation of GIRD is thought to result from chronic eccentric loading to the posterior capsule, which prolongs increased fibroblastic activity during the healing response.[6] Several groups[15,16,31] agreed that the chronic stress of the overhead throw and the excessive repetitions may predispose the shoulder girdle to injury and that GIRD may be the "seminal event" for a cascade of pathologic changes in the throwing shoulder.[6,32] This posterior capsular thickening is thought to alter the arthrokinematics of the humeral head by forcing it in a posterior-superior direction.[33,34] Shifting the glenohumeral axis of rotation posterior and superior is believed to put the shoulder at risk for SLAP (superior labrum anterior to posterior) lesions, rotator cuff tears, and internal impingement syndrome.[15,35]

In our study, GIRD was less in high school than in collegiate baseball players. Our finding supports that of previous researchers,[12] who demonstrated a correlation between loss of internal rotation and years of play in junior elite tennis. Burkhart et al[15] believed that the primal event in developing a "shoulder at risk" is GIRD. They suggested that GIRD stresses and inhibits the scapular stabilizing muscles, which eventually leads to scapular dyskinesis. Our data demonstrate that collegiate baseball players, who presumably have endured more throwing exposures, have both increased amounts of GIRD and alterations in scapular motion. However, the progression of these adaptations cannot be ascertained from this study. Therefore, if GIRD and scapular alterations (decreased upward rotation and increased anterior tilting and protraction) are identified and treated early, further progression of these changes and even injury may be prevented.

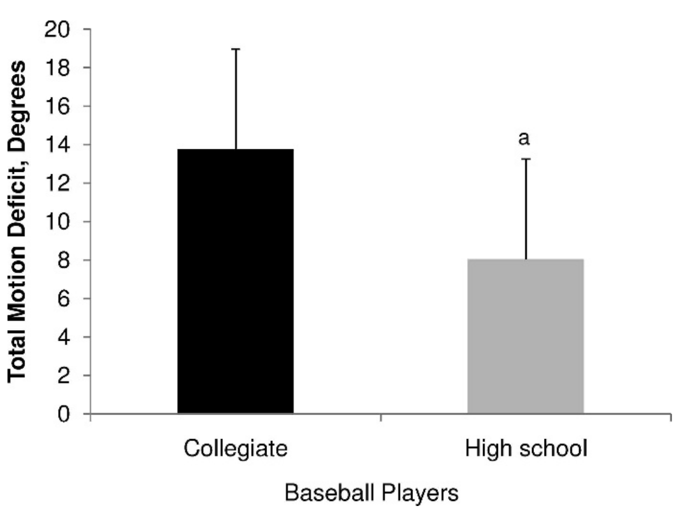

Figure 5. Total motion deficits in collegiate versus high school baseball players. [a] Difference between collegiate and high school players was significant ($P < .05$).

Table 2. Scapular Upward Rotation Differences in Collegiate and High School Baseball Players, Mean ± SD, °

Position	Baseball Players	
	Collegiate	High School
0°	2.40 ± 4.7	−1.79 ± 2.47[a]
60°	3.32 ± 5.87	0.929 ± 5.64
90°	3.03 ± 5.36	2.41 ± 6.10
120°	3.18 ± 4.81	1.83 ± 4.63

[a] Difference between collegiate and high school players ($P < .05$).

Glenohumeral External Rotation Gain

The ERG was greater in high school than in collegiate baseball players. Two groups[31,36] suggested that repetitive overhead motions cause anterior capsule stretching, which is demonstrated by increases in external rotation. One possible explanation for the present results may be tightness of the pectoralis major muscle or any of the large internal rotators (or both) in the collegiate cohort. We recorded external-rotation measurements with the scapula stabilized, which may have limited total external rotation. Evidence for this theory is provided by investigators[37] who observed increases in internal rotation strength over the course of a swimming season. We did not measure pectoralis tightness, and therefore can only speculate about this theory. More studies are warranted to examine the effect of pectoralis tightness on ERG. Less ERG may also mitigate the changes in TMD seen in the collegiate group. Clinically, this suggests that repetitive overhead throwing may not cause anterior capsule laxity or it may only occur later in the career of overhead throwers. Additional

Table 3. Scapular Upward Rotation in Collegiate and High School Baseball Players, Mean ± SD, °

Scapular Upward Rotation	Position	Baseball Players	
		Collegiate	High School
Dominant arm	0°	7.17 ± 4.36	1.93 ± 3.45
	60°	16.07 ± 6.46	16.85 ± 5.38
	90°	27.42 ± 5.58	31.53 ± 5.77[a]
	120°	39.22 ± 4.21	42.2 ± 4.82[a]
Nondominant arm	0°	4.81 ± 3.0	3.43 ± 2.8
	60°	13.05 ± 5.72	15.55 ± 4.78
	90°	24.69 ± 5.37	28.62 ± 4.28[a]
	120°	36.37 ± 4.63	39.81 ± 3.42[a]

[a] Difference between collegiate and high school players ($P < .05$).

Table 4. The Kibler Lateral Scapular Slide Difference in Collegiate and High School Baseball Players, Mean ± SD, °

Position	Baseball Players	
	Collegiate	High School
0°	0.408 ± 1.02	0.008 ± 0.643
Hands on hips	0.793 ± 1.21	0.028 ± 0.951[a]
90°	1.58 ± 1.52	0.223 ± 0.982[a]

[a] Difference between collegiate and high school players ($P < .05$).

research is needed before pectoralis stretching can be suggested as a therapeutic exercise in this population.

Glenohumeral Total Motion Difference

Wilk et al[18] proposed the total motion concept, suggesting that if total motion is equal bilaterally, any change in the arc of motion is due to humeral retroversion and therefore should not be a concern. We observed that high school players had less TMD than collegiate baseball players. This is presumably because of GIRD rather than bony remodeling.[18,38–40] Because internal rotation was less in collegiate players, the larger GIRD should only be ascribed to soft tissue changes.[41] As stated previously, the soft tissue adaptation to chronic distractive posterior glenohumeral forces is thought to be a tightened, thickened posterior capsule.[15] However, other authors[9,10] have generalized this adaptation to posterior shoulder tightness, which may include posterior rotator cuff and posterior capsular tightness. These soft tissue adaptations have also been associated with changes in scapular upward rotation and protraction.[5,6,21] The observed alteration in TMD may suggest that posterior shoulder stretching is warranted to help minimize any further decreases that may be caused by posterior shoulder tightness.

Scapular Upward Rotation Difference

Scapular dyskinesis is commonly linked to glenohumeral joint injury in the overhead athletic population.[5,11,19–21] A decrease in scapular upward rotation is thought to decrease the subacromial space and may cause subacromial impingement at greater degrees of glenohumeral abduction.[42–44] Recently, a number of authors[24,42,45,46] have objectively measured scapular upward rotation in overhead athletes using the digital inclinometer.

Our results revealed that scapular upward rotation differences at rest were greater in collegiate than in high school athletes. This finding is likely because of variability in participants' resting posture. Previous investigators[7,32,42,46–50] have found that scapular upward rotation at the resting position ranges from −2° to 5° in healthy volunteers because of posture. Slouching, rounded shoulders, and increased thoracic kyphosis place the scapula in a resting position with altered upward rotation rather than an upright posture.[49,50] At 90° and 120° of glenohumeral abduction, high school throwers had more scapular upward rotation than their collegiate counterparts on both the dominant and nondominant sides. Decreased active scapular upward rotation causes "scapular lag" with abduction and approximates the acromion closer to the leading edge of the rotator cuff. Presumably, the decreased upward rotation during active shoulder abduction is due to inhibition of scapular rotators, especially the serratus anterior and lower trapezius.[5,29] The decreases in nondominant-side scapular upward rotation may suggest a negative cross-transfer effect of the scapular stabilizers' neuromuscular control. Cross-transfer effects have been associated with increased neuromuscular strength and endurance in the nondominant arm due solely to training in the dominant arm.[51–53] Our findings may indicate that cross-transfer is present with inhibitory effects as well. More studies are warranted to further investigate this observation. Clinically, the results suggest that bilateral scapular strengthening should be performed to help combat the decreases in upward rotation that may place the athlete at increased risk for injury.

Scapular Protraction Difference

Scapular protraction is critical to overall performance in overhead throwing. During the deceleration or follow-through phases of the overhead throw, the scapula must protract around the thoracic wall to help dissipate the large forces placed on the glenohumeral joint.[5,11] Patients with shoulder injuries also present with scapular dyskinesis, such that the scapula is observed to be in a more protracted and internally rotated position.[5,6,54] Kibler[5] stated that throwers with significant GIRD, in an effort to follow through effectively, bring their scapulae "up and around" the thoracic cage to gain humeral internal rotation. This, in time, may also increase scapular protraction and upward rotation at rest as a result of soft tissue adaptation. We found that collegiate players (who also had greater GIRD) presented with more scapular protraction than high school players. A number of authors[5,9,43,55,56] have suggested that increased protraction coupled with GIRD is likely to increase subacromial impingement, potentiate anterior instability by increasing scapular anterior tilting, decrease rotator cuff strength, and promote internal impingement. Posterior shoulder stretching coupled with scapular strengthening may prevent further progression of scapular protraction, which has been shown to decrease the subacromial space.[57]

Limitations

Some limitations to this study should be acknowledged. First, pitchers and position players were analyzed together. We know that pitchers subject their shoulders to additional stress because of the high number of repetitions during each game. However, in a recent study conducted in our laboratory using the current methods, pitchers had increased GIRD and decreased total motion compared with position players. No differences were observed between pitchers and position players for scapular measurements.[58] Next, throwing exposures were not catalogued. A basic assumption is that collegiate throwers have subjected their shoulders to more throwing exposures. However, we have no direct data to validate this. Also, only 2 of the possible 5 degrees of freedom were measured for the scapula. This is a limitation because of the potential injury risk from alterations in the other scapular motions. Yet to our knowledge, scapular upward rotation and protraction are the only valid and reliable measurements that can be observed clinically.[5,19,24,48] Currently, a 3-dimensional electromagnetic tracking system can be used to measure all 5 degrees of scapular motion. However, this technique does not translate well to the clinician, and questions remain as to its validity and reliability because of skin motion between the sensor and the scapula.[59] For scapular protraction, the distance from the inferior angle of the scapula to the spinous process is measured. One potential problem with this measurement is that if less scapular upward rotation is present, the inferior angle may be closer to the spinous process only because of a change in upward rotation and not because of a change in protraction. This would yield a scapular protraction measurement that is less than on the nondominant side. Methods should be developed to account for this measurement limitation. New clinical techniques to assess the other degrees of freedom at the scapula would be beneficial and add clarity to the results we observed. Finally, glenohumeral and scapular muscle strength were not assessed and may play a role in the alterations that were observed between collegiate and high school baseball players.

CONCLUSIONS

Division I collegiate baseball players demonstrated greater GIRD, TMD, and scapular protraction than their high school counterparts. They also demonstrated less ERG and scapular upward rotation. Our findings suggest that less TMD caused by GIRD may be the mechanism resulting in compensatory scapular motions. A dose-response relationship of GIRD's effect on scapular dyskinesis may exist, with increasing exposure to GIRD presenting with a greater likelihood of scapular positional changes. Scapular upward rotation and protraction changes may decrease rotator cuff efficiency, increase stress on the anterior capsular restraints, and potentiate internal impingement. Early efforts to minimize internal-rotation deficits in high school may prevent the development of scapular malposition and its negative consequences on the rotator cuff and glenoid labrum integrity.

ACKNOWLEDGMENTS

Help with participant recruitment was received from Fran Murphy and Susan Mills, Archbishop Carroll High School, and James Sherman, University of Delaware.

REFERENCES

1. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman PH. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *Am J Sports Med*. 1988;16(6):577–585.
2. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc*. 2002;34(12):2052–2056.
3. 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.
4. 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.
5. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med*. 1998;26(2):325–337.
6. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, part III. The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003;19(6):641–661.
7. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular position and orientation in throwing athletes. *Am J Sports Med*. 2005;33(2):263–271.
8. Wilk KE, Macrina L, Porterfield R, Harker P, McMichael CS, Andrews JR. Loss of internal rotation and the correlation to shoulder injuries in professional baseball pitchers. Paper presented at: American Orthopaedic Society of Sports Medicine annual meeting; July 10–13, 2008; Orlando, FL.
9. 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.
10. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med*. 2000;28(5):668–673.
11. Meister K. Injuries to the shoulder in the throwing athlete, part one: biomechanics/pathophysiology/classification of injury. *Am J Sports Med*. 2000;28(2):265–275.
12. 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.
13. Ellenbecker TS, Roetert EP, Piorkowski PA, Schulz DA. Glenohumeral joint internal and external rotation range of motion in elite junior tennis players. *J Orthop Sport Phys Ther*. 1996;24(3):336–341.
14. Thomas SJ, Swanik KA, Swanik CB, Huxel KC. Internal rotation and scapular position changes following competitive high school baseball. Paper presented at: American Orthopaedic Society for Sports Medicine annual meeting; June 29–July 2, 2006; Hershey, PA.
15. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, part I. Pathoanatomy and biomechanics. *Arthroscopy*. 2003;19(4):404–420.
16. Spigelman TH, Swanik KA, Hamstra KL, Swanik CB. Glenohumeral range of motion in pre-pubescent swimmers over a twelve-week season [abstract]. *J Athl Train*. 2003;38(suppl 2):S71–S72.
17. Thomas SJ, Swanik KA, Swanik CB, Huxel KC. Glenohumeral rotation and scapular position change following competitive high school sports [abstract]. *J Athl Train*. 2007;42(suppl 2):S22.
18. 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.
19. Kibler WB. Role of the scapula in the overhead throwing motion. *Contemp Orthop*. 1991;22(5):525–532.
20. Warner JJP, Micheli LJ, Arslenian LE, Kennedy J, Kennedy R. Scapulothoracic motion in normal shoulders and shoulders with glenohumeral instability and impingement syndrome: a study using Moire topographic analysis. *Clin Orthop Relat Res*. 1992;285:191–199.
21. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther*. 2006;36(7):485–494.
22. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech*. 1999;32(12):1371–1375.
23. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res*. 2005;19(1):231–240.
24. Johnson MP, McClure PW, Karduna AR. New method to assess scapular upward rotation in subjects with shoulder pathology. *J Orthop Sports Phys Ther*. 2001;31(2):81–89.
25. Awan R, Smith J, Boon AJ. Measuring shoulder internal rotation range of motion: a comparison of 3 techniques. *Arch Phys Med Rehabil*. 2002;83(9):1229–1234.
26. Kibler WB. Management of the scapula in glenohumeral instability. *Tech Shoulder Elbow Surg*. 2003;4(3):89–98.
27. 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.

28. Abboud JA, Soslowsky LJ. Interplay of the static and dynamic restraints in glenohumeral instability. *Clin Orthop Relat Res*. 2002;400:48–57.
29. Pink MM. Understanding the linkage system of the upper extremity. *Sports Med Arthrosc Rev*. 2001;9(1):52–60.
30. Pappas AM, Zawacki RM, Sullivan TJ. Biomechanics of baseball pitching: a preliminary report. *Am J Sports Med*. 1985;13(4):216–222.
31. Jobe FW, Kvitne RS, Giangarra CE. Shoulder pain in the overhand or throwing athlete: the relationship of anterior instability and rotator cuff impingement. *Orthop Rev*. 1989;18(9):963–975.
32. Thomas SJ, Swanik KA, Swanik CB, Huxel KC. Glenohumeral rotation and scapular position change after a single high school female sports season. *J Athl Train*. 2009;44(3):230–237.
33. Clabbers KM, Kelly JD, Bader D, et al. Effect of posterior capsule tightness on glenohumeral translation in the late-cocking phase of pitching. *J Sport Rehabil*. 2007;16(1):41–49.
34. Huffman GR, Tibone JE, McGarry MH, Phipps BM, Lee YS, Lee TQ. Path of glenohumeral articulation throughout the rotational range of motion in a thrower's shoulder model. *Am J Sports Med*. 2006;34(10):1662–1669.
35. Morgan CD, Burkhart SS, Palmeri M, Gillespie M. Type II SLAP lesions: three subtypes and their relationships to superior instability and rotator cuff tears. *Arthroscopy*. 1998;14(6):553–565.
36. Jobe CW, Pink MM, Jobe FW. Anterior shoulder instability, impingement, and rotator cuff tear: theories and concepts. In: Jobe FW, ed. *Operative Techniques in Upper Extremity Sports Injuries*. St. Louis, MO: Mosby; 1996:164.
37. Ramsi M, Swanik KA, Swanik CB, Straub S, Mattacola CG. Shoulder-rotator strength of high school swimmers over the course of a competitive season. *J Sport Rehabil*. 2004;13(1):9–18.
38. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk KE. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med*. 2002;30(3):354–360.
39. 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.
40. Kronberg M, Brostrom LA, Soderlund V. Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion. *Clin Orthop Relat Res*. 1990;253:113–117.
41. Edelson G. The development of humeral head retroversion. *J Shoulder Elbow Surg*. 2000;9(4):316–318.
42. Su KPE, Johnson MP, Gracely EJ, Karduna AR. Scapular rotation in swimmers with and without impingement syndrome: practice effects. *Med Sci Sports Exerc*. 2004;36(7):1117–1123.
43. Lukasiewicz AC, McClure PW, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther*. 1999;29(10):574–586.
44. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther*. 2000;80(3):276–291.
45. Mourtacos SL, Sauers EL, Downar JM. Adolescent baseball players exhibit differences in shoulder mobility between the throwing and non-throwing shoulder and between divisions of play [abstract]. *J Athl Train*. 2003;38(suppl 2):S72.
46. Downar JM, Sauers EL. Clinical measures of shoulder mobility in the professional baseball player. *J Athl Train*. 2005;40(1):23–29.
47. Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. *J Orthop Sports Phys Ther*. 1996;24(2):57–65.
48. Borsa PA, Timmons MK, Sauers EL. Scapular-positioning patterns during humeral elevation in unimpaired shoulders. *J Athl Train*. 2003;38(1):12–17.
49. Finley MA, Lee RY. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. *Arch Phys Med Rehabil*. 2003;84(4):563–568.
50. Kebaetse M, McClure PW, Pratt NA. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. *Arch Phys Med Rehabil*. 1999;80(8):945–950.
51. Shaver LG. Cross transfer effects of conditioning and deconditioning on muscular strength. *Ergonomics*. 1975;18(1):9–16.
52. Yasuda Y, Miyamura M. Cross transfer effects of muscular training on blood flow in the ipsilateral and contralateral forearms. *Eur J Appl Physiol Occup Physiol*. 1983;51(3):321–329.
53. Yuza N, Ishida K, Miyamura M. Cross transfer effects of muscular endurance during training and detraining. *J Sports Med Phys Fitness*. 2000;40(2):110–117.
54. Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. *Phys Ther*. 2006;86(4): 549–557.
55. Hébert LJ, Moffet H, McFadyen BJ, Dionne CE. Scapular behavior in shoulder impingement syndrome. *Arch Phys Med Rehabil*. 2002; 83(1):60–69.
56. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech (Bristol, Avon)*. 2003;18(5):369–379.
57. Solem-Bertoft E, Thuomas KA, Westerberg CE. The influence of scapular retraction and protraction on the width of the subacromial space: an MRI study. *Clin Orthop Relat Res*. 1993;296:99–103.
58. Thomas SJ, Swanik KA, Swanik CB. Internal rotation and total motion differences: a comparison of baseball pitchers and position players [abstract]. *J Athl Train*. 2008;43(suppl 2):S21.
59. McClure PW, Michener LA, Sennett B, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg*. 2001;10(3):269–277.

Address correspondence to Stephen J. Thomas, MEd, ATC, McKay Orthopaedic Research Laboratory, University of Pennsylvania, 424 Stemmler Hall, 36th Street and Hamilton Walk, Philadelphia, PA 19104-6081. Address e-mail to sjthomasatc@gmail.com.