Scapular Position and Orientation in Throwing Athletes

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Background: Despite the recognized importance of proper 3-dimensional motion of the scapula in throwers, minimal research has quantified scapular position and orientation in throwing athletes.

Hypothesis: Throwing athletes exhibit scapular position and orientation differences when compared to nonthrowing control subjects.

Study Design: Descriptive laboratory study.

Methods: Scapular position and orientation during scapular plane humeral elevation were assessed with electromagnetic tracking in a group of 21 throwing athletes and 21 control subjects. Scapular upward/downward rotation, internal/external rotation, anterior/posterior tipping, elevation/depression, and protraction/retraction were assessed.

Results: The throwing athletes demonstrated significantly increased upward rotation, internal rotation, and retraction of the scapula during humeral elevation. No differences in anterior/posterior tipping and elevation/depression were present.

Conclusions: The results indicate that throwing athletes have scapular position and orientation differences compared to nonthrowing athletes. This suggests that throwers develop chronic adaptation for more efficient performance of the throwing motion.

Clinical Relevance: Clinicians evaluate scapular position, orientation, and movement in throwing athletes as part of the evaluation of shoulder injuries associated with the throwing motion. The current study provides clinicians with an understanding of the types of adaptations that may be observed in normal, healthy throwing athletes.

Keywords: scapula; kinematics; throwers; electromagnetic tracking

During throwing, the scapula must act as the stable base of support between the humerus and trunk while still allowing for the high degree of movement needed from the upper extremity. This is accomplished by the scapula's ability to move in 3 dimensions (3D) about the trunk while still maintaining glenoid-humeral alignment and proper angulation of the humerus with the trunk.[4,14,15]

To maintain joint congruency, the scapula has a high degree of mobility that includes its ability to upwardly/downwardly rotate, internally/externally rotate, tip anteriorly/posteriorly, elevate/depress, and protract/retract on the trunk.[13,21] Commonly, protraction/retraction, elevation/depression, and upward/downward rotation are 3 groups of scapular movement that are described as being important for the throwing motion. During throwing, the scapula must retract to facilitate the cocking position followed by protraction to achieve acceleration and subsequent deceleration.[4,14] Coordinated elevation and upward rotation of the scapula with the humerus is important for maintaining sufficient subacromial space as the humerus is elevated to approximately 90° during the throwing motion, thus avoiding impingement of the rotator cuff in this position.[5,8,9,14] Proper 3D position of the scapula relative to the humerus and trunk is also important for muscle function because the scapula acts as the common point of attachment of the rotator cuff and primary humeral movers such as the biceps, deltoid, and triceps, as well as several scapular stabilizers. Poor position and movement of the scapula can lead to alterations to the relationship between length and tension of each muscle, thus adversely affecting muscle force generation.

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No potential conflict of interest declared. See Acknowledgment for funding information.

The American Journal of Sports Medicine, Vol. 33, No. 2
DOI: 10.1177/0363546504268138

Altered scapular orientation has been implicated in shoulder injury. Ludewig and Cook[17] assessed scapular kinematics using an electromagnetic tracking device in patients with subacromial impingement. Their results demonstrated both decreased upward scapular rotation and decreased posterior tipping during humeral elevation in the patients with subacromial impingement. Similar results were reported by Lukasiewicz et al,[20] in that patients with symptomatic subacromial impingement had less posterior tipping as well as less scapular elevation. In throwing athletes, Burkhart et al and Kibler have provided a thorough description of how 3D scapular dyskinesis is associated with subacromial impingement, labral abnormality, and rotator cuff tears.[3,4,14,15]

Despite the recognized importance of proper 3D motion of the scapula in throwers, little research to date has examined the scapular position and orientation in throwing athletes. In a series of studies, Downar et al, Mourtacos et al, and Sauers et al[6,25,28] assessed scapular upward rotation in baseball players of various skills. Their results demonstrated that in both Little League–aged players (10-13 years of age) and professional baseball players, the throwing shoulder demonstrated more upward rotation of the scapula than the nonthrowing shoulder.[6,25,28] Although these findings related to upward scapular rotation provide clinicians with valuable insight into the scapular movement patterns present in throwers, scapular movement entails more motions than just scapular upward rotation. In addition, scapular dysfunction is often implicated as a contributor to shoulder injury in throwing athletes. As part of the injury evaluation process, clinicians will visually observe scapular motion during humeral elevation in hopes that dysfunction can be identified. Despite the fact that scapular examination is often included as part of the injury evaluation process, no research to date has described what scapular motion patterns are present in healthy throwing athletes. Thus, observing dysfunction may be difficult given that the normative data necessary for comparison are minimal. No one to date has described the 3D scapular positions and orientations present in throwing athletes. The purpose of this study was to measure and compare 3D scapular position and orientation between competitive throwing athletes and a nonthrowing control group during scapular plane humeral elevation. It was hypothesized that in addition to the chronic adaptation in scapular upward rotation reported in the literature,[6,25,28] movement adaptations in internal/external rotation, anterior/posterior tipping, elevation/depression, and protraction/retraction will also be present.

MATERIALS AND METHODS

Subjects

Forty-two volunteers encompassing 2 groups participated in the current study. A group of throwing athletes consisted of 21 male subjects who had been participating in organized, competitive baseball for at least the past 5 years. The average duration of participation of the throwing group was 13.71 ± 2.43 years. This group consisted of 9 pitchers and 12 field position players (6 infielders and 6 outfielders). A control group consisted of 21 male subjects who were matched according to age, height, mass, and dominant limb to the subjects in throwing group but with no significant history of participation in overhead athletics. Potential control group subjects were excluded if they had a history of competitive participation or were currently active in traditional overhead sports such as baseball, softball, racket sports, and swimming. All subjects in the control group were physically active at least 2 to 3 times per week. All participants in the current study were free of significant upper extremity injury history (ie, no history of physician examination for upper extremity injury). Complete subject demographics appear in Table 1.

TABLE 1
Subject Demographics

	Throwers Group		Control Group	
	Mean	±SD	Mean	±SD
Age, y	21.57	1.77	24.64	4.04
Height, m	1.80	0.60	1.76	0.07
Mass, kg	86.86	11.77	78.01	11.71

Instrumentation

Scapula and humerus kinematic data were collected using the Motion Monitor (Innovative Sports Training Inc, Chicago, Ill) electromagnetic tracking device. The Motion Monitor software uses data conveyed by electromagnetic receivers for the calculation of receiver position and orientation relative to an electromagnetic transmitter. The specific hardware used in this investigation consisted of an extended-range direct current transmitter and 4 receivers. The instrumentation sampling frequency used for all kinematic assessments in the current study was 100 Hz. Determination of position and orientation accuracy performed in our research laboratory yielded a root mean square error of 0.004 m and 0.3°, respectively.

A Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY) was used in the current study before kinematic assessment to determine the amount of load that each subject would hold during the kinematic trials.[27] The Biodex system uses a dynamometer containing strain gauges and potentiometers to measure torque output from almost any joint. Torque can be measured through concentric, eccentric, and isometric resistance at dynamometer speeds ranging from 0°/s up to 500°/s. In the current study, isometric torque of shoulder elevation was quantified.

Procedures

Before testing, each subject signed an informed consent form as required by the University Institutional Review Board. Next, each subject's maximum elevation torque

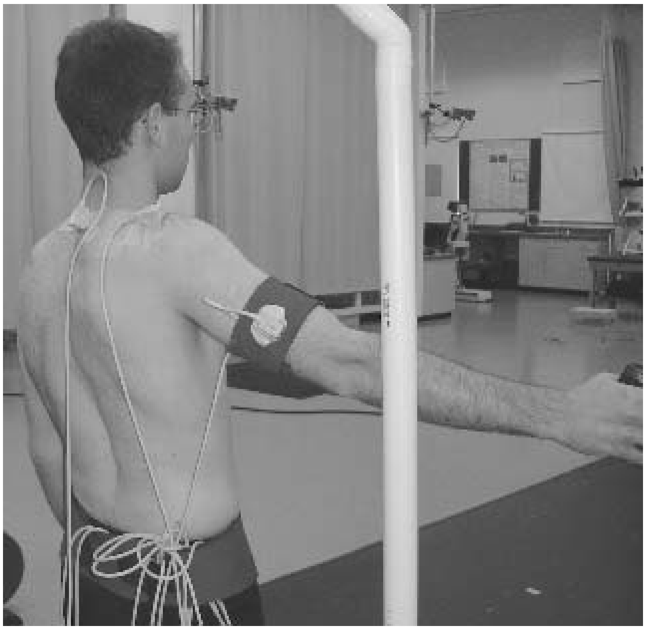

Figure 1. A participant performing humeral elevation during collection.

output was recorded with the Biodex System 3 dynamometer. These data were subsequently used to determine the amount of mass that would be held by each subject during the scapular kinematic assessment trials.[27] Each subject was seated in an upright position on the Biodex System 3 isokinetic device with his or her dominant upper extremity positioned in the scapular plane (30° anterior to the frontal plane), 20° of elevation, and the axis of glenohumeral joint rotation aligned with the axis of rotation of the dynamometer. The dominant limb was defined as the limb the subject uses to throw a ball, and this limb was used for all testing. After 3 warm-up trials, testing consisted of three 5-second maximum, isometric elevation contractions. Each repetition was separated by a 10-second rest period. The mean torque of the 3 trials produced during the isometric elevation test was normalized to the length of the subject's arm (acromion to the first web space with the arm fully extended). Twenty-five percent of the normalized torque was the mass held during the humeral elevation trials.

After mass determination, each subject had 3 electromagnetic receivers secured to various anatomical landmarks for kinematic analysis of the scapula and humerus (Figure 1). Electromagnetic receivers were secured with double-sided adhesive disks (3M Health Care, St. Paul, Minn) and hypoallergenic tape (to further reduce receiver-to-skin movement) superficial to the seventh cervical vertebra and on the flat, broad portion of the acromion on the scapula. A third electromagnetic receiver was secured to the midportion of the humerus using a neoprene cuff. The receiver positions of the scapula and humerus were previously validated using bone-fixed markers and shown to accurately represent movement of their respective segments.[13,19] A fourth receiver was attached to a stylus that was used for the digitization of landmarks described in the subsequent section.[22,23]

While the subjects stood with their arms at their sides, several bony landmarks on the thorax, scapula, and humerus of the dominant limb were palpated and digitized with the stylus. The digitized landmarks appear in Table 2. Digitization of the bony landmarks allowed transformation of the receiver data from a global coordinate system to anatomically based local coordinate systems (Figure 2). Testing consisted of subjects holding the predetermined load (described above) in their hands with the forearm rotated so that the thumb was pointing superior while elevating the humerus in the scapular plane. Humeral elevation/depression began with the arm in the resting position at the subject's side (referred to as 0° of elevation throughout this article), progressing toward full elevation (maximum amount of elevation each subject could obtain), and then returning to the resting position. Humeral elevation and depression in the scapular plane was maintained through the use of a guide tube (Figure 1). Each subject performed 10 continuous repetitions lasting 4 seconds each (2 seconds to reach maximum elevation and 2 seconds to return to the starting position) with assistance from a metronome. Reliability of the scapulohumeral kinematic protocol used in the current study has been recently presented (intraclass correlation coefficient, .63-.96).[26] The elevation/depression task used in the current study was chosen because it is a noninvasive, in vivo, validated means of assessing scapular kinematics[13]; it replicates a substantial amount of previously published research that has assessed scapular position and orientation, making comparison with previous work feasible; it is sensitive to show changes associated with shoulder abnormality (subacromial impingement)[17,18] and scapular stabilizer muscle fatigue[32]; and it mimics how clinicians typically observe scapular dyskinesis during shoulder injury evaluation.[16]

Data Reduction and Analysis

Raw kinematic data were filtered with a low-pass fourth-order zero-phase shift filter with a cutoff frequency of 10 Hz. Receiver position and orientation data of the thoracic, scapular, and humeral receivers were transformed into a local coordinate system for each of the respective segments. Definitions of the local coordinate systems can be obtained from Table 3 and observed in Figure 2. The coordinate systems used were in accordance with recommendations from the International Shoulder Group of the International Society of Biomechanics.[33] In general, 2 points first described the longitudinal axis of a segment, and a third point defined the plane. A second axis is defined perpendicular to the plane, and the third axis is defined as perpendicular to both of the first 2 axes. When standing in a neutral stance, the orthogonal coordinate system for each segment is vertical (y-axis), horizontal to the right (x-axis), and posterior (z-axis). Matrix transformations for each of the segments were used to move from the global to local coordinate systems, producing a 4 × 4 position and orientation matrix.

TABLE 2
Description of Bony Landmarks

Bony Landmarks	Description of Palpation Point
Thorax	
Eighth thoracic spinous process (T8)	Most dorsal point
Processus xiphoideus (PX)	Most caudal point of sternum
Seventh cervical spinous process (C7)	Most dorsal point
Incisura jugularis (IJ)	Most cranial point of the sternum (suprasternal notch)
Scapula	
Angulus acromialis (AA)	Most lateral-dorsal point of scapula
Trigonum spinae (TS)	Midpoint of triangular surface on the medial border of the scapula in line with the scapular spine
Angulus inferior (AI)	Most caudal point of scapula
Humerus	
Medial epicondyle (ME)	Most medial point on the medial epicondyle
Lateral epicondyle (LE)	Most lateral point on the lateral epicondyle
Glenohumeral joint center (GH)[a]	

[a]The glenohumeral joint center was not palpated but rather estimated with a least squares algorithm for the point on the humerus that moves the least during several short arc humeral movements.[11,31]

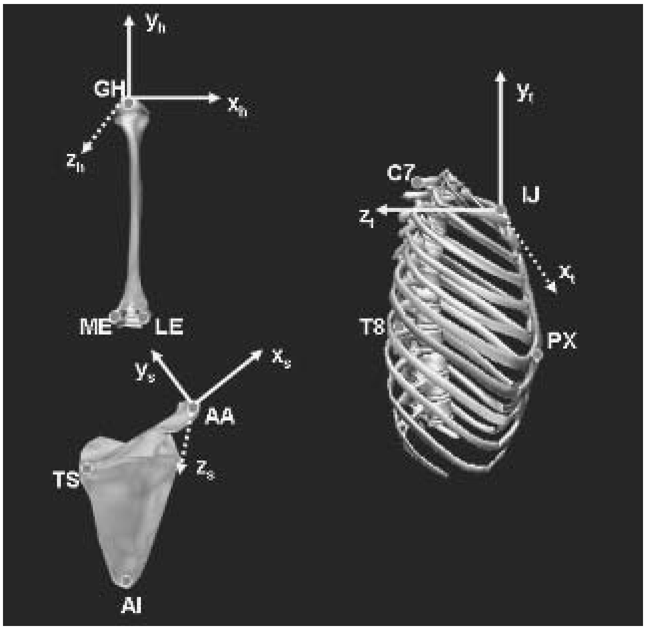

Figure 2. Bony landmarks and local coordinate systems of the trunk, scapula, and humerus. See Table 2 for a description of the bony landmarks and Table 3 for definitions of the local coordinate systems.

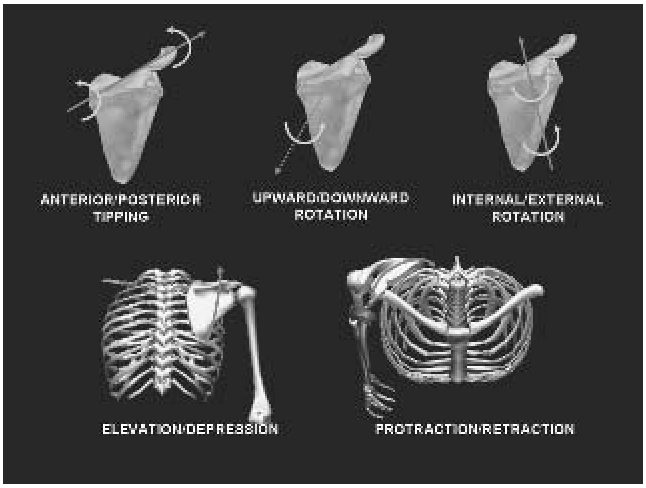

Figure 3. Scapular position and orientations assessed in the current study.

Euler angle decompositions were used to determine the scapular and humeral orientation with respect to the thorax. Orientation of the scapula was determined as rotation about the y-axis of the scapular (internal/external rotation), rotation about the z-axis of the scapula (upward/downward rotation), and rotation about the x-axis of the scapula (anterior/posterior tipping) (Figure 3). Humeral orientation was determined as rotation about the y-axis of the humerus (plane of elevation), rotation about the z-axis (elevation), and rotation about the y-axis (axial rotation). Each of these rotations was chosen based on the recommendations of the International Shoulder Group.[33] The Euler angle sequences were used to most closely represent clinical definitions of movements and to decrease mathematical inconsistencies (ie, gimble lock).[12,33]

Position of the scapula was also described. Scapulothoracic movement does not involve any bone-to-bone contact, and the scapula does not attach via direct contact to the thorax. The only attachment of these 2 segments is via the clavicle, a rigid body with a fixed length. As such, the position of the scapula can be described by 2 degrees of freedom, as if in spherical space, by both elevation/depression and protraction/retraction.[13,21] The positions of the angulus acromialis (AA) and incisura jugularis (IJ) points with respect to the global coordinate system (tracked by the scapular and thoracic receivers, respectively) were used to calculate a vector from the IJ point to the AA point. The

TABLE 3
Definitions of Local Coordinate Systems

Local Coordinate System	Axis	Definition[a]
Thorax	y_t	Vector from the midpoint of PX and T8 to the midpoint between IJ and C7
	x_t	Vector perpendicular to the plane fitted by midpoint of PX and T8, the midpoint of IJ and C7, and IJ
	z_t	Vector perpendicular to x_t and y_t
	Origin	IJ
Scapula	x_s	Vector from TS to AA
	y_s	Vector perpendicular to the plane fitted by TS, AA, and AI (scapular plane)
	z_s	Vector perpendicular to x_s and y_s
	Origin	AA
Humerus	y_h	Vector from midpoint of ME and LE to GH
	x_h	Vector perpendicular to the plane fitted by GH, ME, and LE
	z_h	Perpendicular to y_h and x_h
	Origin	GH

[a]PX, processus xiphoideus; T8, eighth thoracic spinous process; IJ, incisura jugularis; C7, seventh cervical spinous process; TS, trigonum spinae; AA, angulus acromialis; AI, angulus inferior; ME, medial epicondyle; LE, lateral epicondyle; GH, glenohumeral joint center.

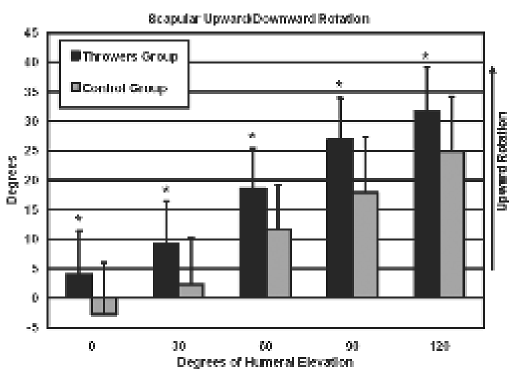

Figure 4. Scapular upward/downward rotation in the throwing and control groups. *, significantly increased upward rotation in the throwing group compared to the control group.

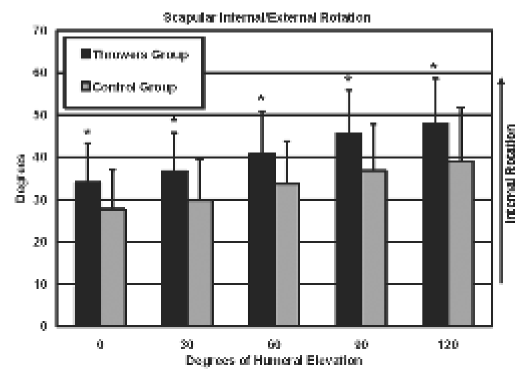

Figure 5. Scapular internal/external rotation in the throwing and control groups. *, significantly increased internal rotation in the throwing group compared to the control group.

angle of this vector relative to the transverse plane that bisects the IJ point represents elevation/depression of the scapula. For protraction/retraction, this vector was projected onto the transverse plane bisecting IJ and is calculated as the angle between this projection and the frontal plane that bisects IJ.

Both the position and orientation of the scapula were analyzed at the initiation of movement (0°), 30°, 60°, 90°, and 120° of humeral elevation. No data above 120° of elevation were analyzed because of the lack of accuracy that could occur.[13] An independent sample *t* test (SPSS version 11.0, SPSS Science Inc, Chicago, Ill) was used to compare group differences for all variables assessed. An α level of .05 was set before all analyses.

RESULTS

The throwing group in the current study demonstrated significantly increased upward rotation of the scapula at 0° (P = .010), 30° (P = .006), 60° (P = .004), 90° (P = .001), and 120° (P = .013) of humeral elevation in the scapular plane (Figure 4). Scapular internal rotation was significantly increased in the throwing group at 0° (P = .039), 30° (P = .027), 60° (P = .027), 90° (P = .011), and 120° (P = .018) (Figure 5). Significant increases in the amount of retraction were present in the throwing group at 90° (P = .050) and 120° (P = .005) of humeral elevation (Figure 6). No significant differences existed between the throwing and control subjects for the anterior/posterior tipping and the elevation/depression variables. The descriptive statistics for all scapular kinematic variables appear in Table 4.

DISCUSSION

The purpose of this study was to measure and compare 3D scapular position and orientation between competitive throwing athletes and a nonthrowing control group during scapular plane humeral elevation. The results indicate

TABLE 4
Scapular Kinematic Data Descriptive Statistics

	Throwing Group		Control Group		
	Mean	±SD	Mean	±SD	*P*
Scapular upward/downward rotation					
0° humeral elevation[a]	4.02	7.46	–2.73	8.74	.010
30° humeral elevation[a]	9.24	7.23	2.34	8.00	.006
60° humeral elevation[a]	18.53	6.88	11.67	7.59	.004
90° humeral elevation[a]	26.90	7.08	18.01	9.36	.001
120° humeral elevation[a]	31.68	7.46	24.88	9.35	.013
Scapular internal/external rotation					
0° humeral elevation[a]	33.92	9.32	27.79	9.24	.039
30° humeral elevation[a]	36.58	9.29	29.85	9.71	.027
60° humeral elevation[a]	40.80	6.88	33.65	10.10	.027
90° humeral elevation[a]	45.60	10.28	36.88	10.93	.011
120° humeral elevation[a]	47.97	10.69	38.97	12.83	.018
Scapular anterior/posterior tipping					
0° humeral elevation	–12.40	8.53	–10.85	5.57	.587
30° humeral elevation	–11.02	6.73	–7.61	4.51	.061
60° humeral elevation	–9.74	7.73	–6.21	5.36	.093
90° humeral elevation	–8.57	8.17	–4.22	6.30	.060
120° humeral elevation	0.083	5.90	3.15	9.74	.117
Scapular protraction/retraction					
0° humeral elevation	–27.87	6.75	–25.80	5.25	.275
30° humeral elevation	–30.87	7.01	–28.94	6.07	.346
60° humeral elevation	–32.94	7.30	–30.25	6.89	.227
90° humeral elevation[a]	–35.82	7.12	–31.62	6.46	.050
120° humeral elevation[a]	–40.94	4.18	–36.13	6.03	.005
Scapular elevation/depression					
0° humeral elevation	0.33	4.31	–2.64	5.91	.070
30° humeral elevation	2.17	4.04	–0.69	6.44	.092
60° humeral elevation	5.50	5.95	3.41	6.17	.271
90° humeral elevation	9.48	6.32	7.40	5.94	.280
120° humeral elevation	12.23	4.32	9.94	5.73	.151

[a]Significant difference between the throwing and control groups.

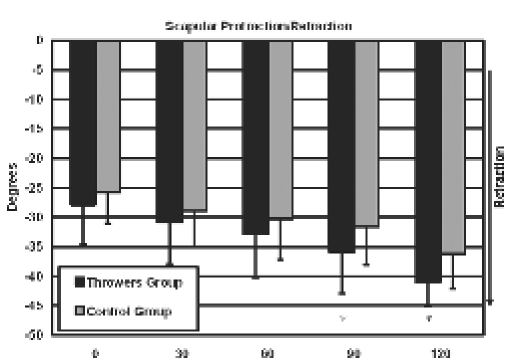

Figure 6. Scapular protraction/retraction in the throwing and control groups. *, significantly increased retraction in the throwing group compared to the control group.

that throwing athletes have scapular position and orientation differences including increased upward rotation, internal rotation, and retraction.

It has been suggested that the presence of sufficient upward rotation during throwing is vital to injury-free performance by clearing the acromion from the underlying subacromial structures, thus preventing subacromial impingement.[14,24] The results suggest that throwers have adapted the amount of upward rotation present in their scapula (Figure 4). These results are consistent with others studies reported in the literature.[6,25,28] Both Sauers et al[28] and Downar et al[6] assessed scapular upward rotation in professional baseball players and demonstrated that the dominant limb has increased scapular upward rotation compared to the nondominant limb. The results of these studies as well as the current study suggest that the increased scapular upward rotation is a chronic adaptation to achieve the subacromial clearance needed during the throwing motion for improved throwing skill and possibly injury prevention.

Loss of upward rotation has been implicated in shoulder injury. Using an electromagnetic tracking device and similar methodology to the current study, Ludewig and Cook[17] demonstrated that patients with subacromial impingement demonstrate decreased upward scapular rotation. Endo et al[7] reported that patients with chronic subacromial impingement exhibit decreased upward rotation at 90° of humeral elevation, a position commonly associated with the impingement zone. Thus, a loss of upward scapular rotation and resulting increased loss in acromial elevation perpetuate impingement of the subacromial structures.

Fatigue of the muscles about the shoulder has been demonstrated to adversely affect scapular movement, specifically upward rotation. Tsai et al[32] assessed scapular kinematics before and after an external rotation fatiguing task. After fatigue, upward rotation, external rotation, and posterior tipping of scapula were decreased. In a population of throwing athletes, Birkelo et al[1] reported that scapular upward rotation and external rotation were significantly decreased after a bout of throwing equivalent to approximately 5 innings. Swimmers demonstrated similar losses of upward rotation after a bout of swimming equivalent to a typical National Collegiate Athletic Association Division I swim practice.[29] In the current study, the throwing athletes demonstrated increased upward rotation, but it must be noted that this was in a population of throwers with no history of shoulder injury or under no influence of fatigue. No studies to date have compared a group of throwing athletes to nonthrowing athletes to determine if a difference in scapular position and orientation existed before fatigue. Future direction should focus on the assessment of scapular kinematics during and after game participation and whether (and when) fatigue results in a decrease in scapular upward rotation.

The throwing athletes in the current study also exhibited increased internal rotation of the scapula during all phases of scapular elevation (Figure 5). Clinically, this motion is commonly described as "scapular protraction" and/or "scapular winging." However, *internal/external rotation* and *protraction/retraction* are often used interchangeably, yet when referring to 3D motion of the scapula, protraction/retraction and internal/external rotation are in fact 2 different sets of motions, unlike the way they are commonly described clinically. As described in the Methods section, internal/external rotation represents motion about the vertical axis of the scapula, whereas protraction/retraction represents the medial-lateral scapular movement around the thorax. The increased internal rotation may be problematic given that scapular internal rotation (described as "protraction" by Solem-Bertoft et al[30]) results in a decrease of the subacromial space[30] and an inability of the greater tuberosity of the humerus to pass freely under the acromion during humeral elevation.[2]

Burkhart et al[4] described the presence of a "SICK" scapula in throwing athletes with labral abnormality, subacromial impingement, and/or rotator cuff lesion complaints. A SICK scapula is an asymmetric malposition of the scapula in which the **S**capula has **I**nferior medial border prominence, **C**oracoid pain and malposition, and dys**K**inesis of movement. A thrower with a SICK scapula exhibits an apparent dropped shoulder to visual inspection, but in fact, the scapula is internally rotated about its vertical axis, resulting in a prominent medial border.[4] The increased scapular internal rotation seen in healthy throwers such as in the current study may account for some of the prominent medial border (scapular internal rotation) present in throwers with a SICK scapula and accompanying shoulder abnormality. Burkhart et al[4] reported that in unpublished data (by P. Donley and J. Cooper), a group of 19 healthy pitchers exhibited no evidence of a SICK scapula or even scapular asymmetry as measured qualitatively with a 20-point SICK scapula visual assessment rating scale, rather than a quantitative biomechanical assessment such as in the current study. Scapular asymmetry in throwers has been quantitatively demonstrated.[6,25,28] The contribution of the scapular adaptations seen in the current study to the SICK scapula seen in the shoulders of injured throwers warrants further investigation.

Like upward and internal rotation, adaptations in scapular retraction also exist in throwing athletes. Increased scapular retraction was present at 90° and 120° of humeral elevation (Figure 6). The data indicate that the scapula moves medially about the trunk, toward the spine at these positions. During the cocking phase of the throwing motion, the arm typically achieves about 90° of humeral elevation, similar to the position at which retraction was increased in the current study.[8-10] Kibler[15] described how scapular retraction is necessary to achieve the cocking position during the throw and tennis serve. In the current study, the increase in retraction may facilitate a maximum cocking position for subsequent explosive acceleration during the throwing motion.

Overall, it appears that throwing athletes develop chronic adaptations that most likely contribute to or result from the throwing motion. Yet it is difficult to determine if the adaptations result in improved throwing skill (ie, increased upward rotation and retraction) or injury prevention (ie, increased upward rotation) or possibly contribute to joint injury (ie, increased internal rotation).

When evaluating the results of the current study, there are several limitations that warrant acknowledgment. Unfortunately, the current study assesses scapular kinematics in throwing athletes during an elevation task and not during actual pitching. The displacement between the scapula and skin would make assessment of the scapula during a ballistic activity such as throwing extremely difficult.[34] If one were to attempt to measure scapular position during throwing, some invasive means (ie, the use of bone pins with either electromagnetic receivers or reflective markers) would most likely be necessary. A study of that nature would provide valuable information, given that very little is known about the scapula during throwing despite its recognized importance.[14,15] A second limitation in the current study is that the nondominant limb was not assessed, thus not allowing for comparison of limbs within subjects. A review of the literature indicates that throwers do demonstrate asymmetry in scapular position (ie, increased upward rotation in the dominant limb).[6,25,28] Yet the studies to date have not included a nonthrowing control group for comparison purposes. A final limitation is that scapular protraction/retraction and elevation/depression were calculated as a vector from the IJ to the AA, projected into the transverse and frontal and planes, respectively. Unlike the current study, previous studies[13,21] have used a vector derived from the IJ and acromioclavicular joint rather than the AA to calculate scapular position. Because those studies have been published, the International

Shoulder Group recommendations have been modified to digitize the AA rather than the acromioclavicular point when digitizing bony scapular landmarks.[33,34] Thus, when comparing the current results to previous published literature, a small amount of discrepancy in the actual scapular position may exist because of differences in bony landmark digitization.

Clinical Implications

Sports medicine clinicians evaluate scapular position, orientation, and movement in throwing athletes on a daily basis as part of the evaluation of shoulder injuries associated with the throwing motion. Yet until now, 3D scapular position and orientation have not been quantified in throwing athletes. It was unknown what positions and orientations are considered normal adaptations present in healthy throwing athletes or alterations associated with injury. The current study provides clinicians with an understanding of the types of adaptations that may be observed in normal, healthy throwing athletes. In addition, this study provides a basis for future comparisons of scapular position and orientation in patients diagnosed with throwing-related labral abnormality, rotator cuff lesions, and impingement. The findings may serve as treatment goals in the rehabilitation of injuries associated with throwing in overhead athletes.

CONCLUSIONS

The results of the current study indicate that throwing athletes have scapular position and orientation differences including increased upward rotation, internal rotation, and retraction compared to nonthrowers. This finding suggests that throwers develop chronic adaptations that most likely contribute to or result from the throwing motion and may result in improved throwing skill, contribute to injury prevention, or possibly contribute to joint injury.

ACKNOWLEDGMENT

This article was funded by the National Football League Charities.

REFERENCES

1. Birkelo JR, Padua DA, Guskiewicz KM, Karas SG. Prolonged overhead throwing alters scapular kinematics and scapular muscle strength. *J Athl Train*. 2003;38:S10-S11.
2. Browne AO, Hoffmeyer PJ, Tanaka S, An KN, Morrey BF. Glenohumeral elevation studied in three dimensions. *J Bone Joint Surg Br*. 1990;72:843-845.
3. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, part I: pathoanatomy and biomechanics. *Arthroscopy*. 2003;19:404-420.
4. 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;19:641-661.
5. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther*. 1993;18:402-408.
6. Downar JM, Sauers EL, Mourtacos SL. Chronic adaptations in the throwing shoulder of professional baseball players. *J Athl Train*. 2002;37:S17-S18.
7. Endo K, Ikata T, Katoh S, Takeda Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. *J Orthop Sci*. 2001;6:3-10.
8. Feltner ME. Three dimensional interactions in a two-segment kinetic chain, part II: application to the throwing arm in baseball pitching. *Int J Sport Biomech*. 1989;5:420-450.
9. 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;32:1371-1375.
10. Fleisig GS, Escamilla RF, Andrews JR, Matsuo T, Satterwhite Y, Barrentine SW. Kinematic and kinetic comparison between baseball pitching and football passing. *J Appl Biomech*. 1996;12:207-224.
11. Harryman DT, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am*. 1990;72:1334-1343.
12. Karduna AR, McClure PW, Michener LA. Scapular kinematics: effects of altering the Euler angle sequence of rotations. *J Biomech*. 2000;33:1063-1068.
13. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. *J Biomech Eng*. 2001;123:184-190.
14. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med*. 1998;26:325-337.
15. Kibler WB. Role of the scapula in the overhead throwing motion. *Contemp Orthop*. 1991;22:525-532.
16. Kibler WB, Uhl TL, Maddux JW, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study. *J Shoulder Elbow Surg*. 2002;11:550-556.
17. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther*. 2000;80:276-291.
18. Ludewig PM, Cook TM. Translations of the humerus in persons with shoulder impingement symptoms. *J Orthop Sports Phys Ther*. 2002;32:248-259.
19. Ludewig PM, Cook TM, Shields RK. Comparison of surface sensor and bone-fixed measurement of humeral motion. *J Applied Biomech*. 2002;18:163-170.
20. Lukasiewicz AC, McClure P, 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;29:574-583; discussion 584-586.
21. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg*. 2001;10:269-277.
22. Meskers CG, Fraterman H, van der Helm FC, Vermeulen HM, Rozing PM. Calibration of the “Flock of Birds” electromagnetic tracking device and its application in shoulder motion studies. *J Biomech*. 1999;32:629-633.
23. Meskers CG, Vermeulen HM, de Groot JH, van Der Helm FC, Rozing PM. 3D shoulder position measurements using a six-degree-of-freedom electromagnetic tracking device. *Clin Biomech (Bristol, Avon)*. 1998;13:280-292.
24. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech (Bristol, Avon)*. 2003;18:369-379.
25. 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. *J Athl Train*. 2003;38:S72.
26. Padua DA, Birkelo JR, Karas SG, Guskiewicz KM, Thigpen CT. Reliability of scapulo-humeral rhythm during dynamic shoulder motion. *Med Sci Sports Exerc*. 2003;35(suppl 1):S62.

27. Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. *J Shoulder Elbow Surg*. 2000;9:519-523.
28. Sauers EL, Keuter G, Schafer MF, Koh JL. Clinical measures of shoulder mobility in professional baseball players: a comparison between pitchers and position players. Paper presented at: 23rd Annual Meeting of the Arthroscopy Association of North America; April 22-25, 2004; Orlando, Fla.
29. Scibek JS, Borsa PA. Swimming practice significantly reduces scapular upward rotation. *J Athl Train*. 2003;38:S11.
30. Solem-Bertoft E, Thomas KA, Westerberg CE. The influence of scapular retraction and protraction on the width of the subacromial space: an MRI study. *Clin Orthop*. 1993;296:99-103.
31. Stokdijk M, Nagels J, Rozing PM. The glenohumeral joint rotation centre in vivo. *J Biomech*. 2000;33:1629-1636.
32. Tsai NT, McClure PW, Karduna AR. Effects of muscle fatigue on 3-dimensional scapular kinematics. *Arch Phys Med Rehabil*. 2003;84:1000-1005.
33. van der Helm FC. *A Standardized Protocol for the Description of Shoulder Motions*. University Park, Pa: International Shoulder Group of the International Society of Biomechanics; 2002.
34. Veeger HE, van der Helm FC, Chadwick EK, Magermans D. Toward standardized procedures for recording and describing 3-D shoulder movements. *Behav Res Methods Instrum Comput*. 2003;35:440-446.