No Effect of Scapular Position on 3-Dimensional Scapular Motion in the Throwing Shoulder of Healthy Professional Pitchers

Amee L. Seitz, Michael Reinold, Robert A. Schneider, Thomas J. Gill, and Charles A. Thigpen

Context: Differences in 3-dimensional (3D) scapular motion have been reported between healthy baseball position players and healthy nonoverhead athletic controls, as well as players diagnosed with shoulder impingement syndrome. These alterations are theorized to be the result of adaptations due to the demands of repetitive throwing. However, comparisons between the throwing and nonthrowing shoulders are commonly used to infer normal motion. Objective: The purpose of this study was to compare 3D scapular kinematics between the throwing and nonthrowing shoulders in asymptomatic professional male baseball pitchers. Design: Cross-sectional study. Setting: Laboratory. Participants: 45 asymptomatic professional baseball pitchers participating without restrictions during preseason training. Interventions: An electromagnetic tracking system was used to assess 3D scapular orientation at rest and during weighted (2.3-kg) shoulder flexion across discrete humeral-flexion angles (rest, 30°, 60°, 90°, 120°, and maximum). Main Outcome Measure: 3D scapular upward/downward rotation (UR/DR), anteroposterior (AP) tilt, and internal/external rotation (IR/ER). Separate mixed-model ANOVAs (Side × Angle) for each scapular motion were used to compare the throwing and the nonthrowing shoulder across all angles. Results: There were significant side-to-side differences with scapular UR/DR (P < .001), AP tilt (P < .001), and IR/ER (P < .001). The throwing scapula displayed greater mean UR (increase = 3.6°, SE = 0.50) and anterior/posterior tilt (increase = 2.1°, SE = 0.60) and less mean IR (decrease = 2.1°, SE = 0.66) than the nonthrowing shoulder averaged across all arm angles. Conclusions: In asymptomatic professional pitchers, the throwing shoulder’s scapular position differs across all arm angles from that of the nonthrowing shoulder, but the motion does not differ. Scapular asymmetry that is consistent throughout arm elevation may be indicative not of pathology but, potentially, of a normal adaptation of the pitching shoulder.

Keywords: kinematics, athletic therapy, motion analysis, sport

Abnormal scapular motion, or scapular dyskinesis,1 has been theorized to contribute to the development of internal impingement, subacromial impingement, labral pathology, and rotator-cuff tears in overhead-throwing athletes.1–5 With humeral elevation, the scapula normally moves in a pattern of upward rotation, external rotation, and posterior tilt.6–9 Normal scapular motion is necessary for healthy shoulder mechanics. The scapula is believed to be a major determinant of how the glenohumeral joint will function during the throwing motion.1

Three-dimensional (3D) scapular kinematics have been shown to differ between healthy competitive baseball players and those with internal impingement3 and between healthy overhead competitive throwers and nonoverhead athletic controls using 3D electromagnetic motion capture.10 Authors of those studies suggest that chronic adaptations occur due to the demands of throwing. However, conclusions are based on results of small cohorts of throwing athletes (11 and 21 subjects) comprising fewer than 50% (15/32) pitchers. Pitchers have unique adaptations in scapular position and orientation compared with position players11 and compile 65% to 80% of all baseball arm injuries.12,13 Potential alterations in scapular kinematics may exist in the pitcher’s throwing shoulder but have yet to be completely defined. Therefore, clinical interpretation of existing data is confounded by the lack of pitchers examined and comparison with the nonthrowing shoulder.

A few studies have identified scapular asymmetry between shoulders in overhead athletes.14,15 However, they were limited to evaluation of scapular orientation and position with resting posture using electromagnetic motion capture or only in static positions of active arm elevation using a digital inclinometer.14,15 Differences
in scapular kinematics during dynamic shoulder movements in pitchers have yet to be determined. Moreover, scapular-motion abnormalities are more evident during dynamic assessment than during static testing. To our knowledge, no study has examined the 3D scapular kinematics between shoulders in professional baseball players, specifically pitchers, during dynamic active arm elevation. The throwing and nonthrowing shoulders are commonly compared in the evaluation of an injured athlete. Understanding potential biomechanical differences between shoulders may provide a more comprehensive understanding of the chronic adaptations that occur in the throwing shoulder and the extent of these adaptations in a population performing at the highest level. Furthermore, this is a necessary step to interpret movement differences in injured pitchers. Therefore, the purpose of this study was to compare 3D shoulder kinematics between the throwing and nonthrowing shoulder in asymptomatic professional pitchers with the hypothesis that the throwing shoulder would present with alterations in scapular motion compared with the nonthrowing shoulder.

Methods

Design

We used a cross-sectional design to answer the research question.

Participants

Forty-five male professional baseball pitchers from 1 organization participated in this study. Participants were screened for eligibility for the study by a certified athletic trainer and physical therapist. Players were eligible if they were over 18 years of age and were participating without restriction in all preseason training and competition (practice and games). Participant characteristics are shown in Table 1. Before testing, eligible participants received an explanation of the testing procedures and read and signed an informed-consent form approved by the University of North Florida Committee for the Protection of Human Subjects. Enrolled study participants completed a questionnaire collecting demographic information and information regarding their baseball-playing history.

Instrumentation

An electromagnetic motion-analysis system (Flock of Birds, Ascension Technology, Inc, Burlington, VT) controlled by Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL) was used to continually assess 3D shoulder kinematic data of throwing and nonthrowing shoulders during humeral elevation in the sagittal plane (flexion) at a sampling rate of 50 Hz. The electromagnetic tracking device consists of an extended-range transmitter affixed to a rigid base, 8 receivers with 1 attached to a stylus used to digitize anatomical landmarks, and a systems electronic unit. The transmitter emits a magnetic field detected by receivers affixed to the thorax, scapula, and humerus. Using consistent data-collection methods, a prior study demonstrated acceptable position (0.7 mm) and orientation (0.27°) error with an electromagnetic motion-analysis system and an extended-range transmitter. Movement analysis of 3D scapular kinematics with electromagnetic tracking using skin-surface receivers has been validated through bone-pin study. Root-mean-square intertrial error of skin-fixed methods using electromagnetic tracking is low, approximately 2°, and is less with humeral elevation in the sagittal plane (flexion) than with elevation in the frontal plane (abduction).

Procedures

All testing was performed before activities within the first 7 days of preseason training in a field-laboratory environment. Five separate electromagnetic receivers were attached to study participants using double-sided tape (3M Health Care, St Paul, MN) and further secured with CoverRoll (Beiersdorf, Norwalk, CT). Elastic wraps were used to further secure the humeral receivers. Following recommendations of the International Society of Biomechanics Shoulder Group, receivers were placed on the thorax, scapula, and humerus. One receiver was placed on the thorax over the spinous process of T3. The scapula receivers were placed over the broad flat surface of the posterolateral acromion of each scapula, and the humeral receivers were placed over the posterior aspect of each humerus distal to the triceps muscle belly.

Once the receivers were applied, participants were asked to stand in a relaxed posture, eyes fixed forward, and feet at a comfortable width apart with their heels parallel to the transmitter for digitization and data collection. Anatomical landmarks were digitized using a mobile receiver attached to a stylus. The digitized bony landmarks identified by palpation included those on the thorax (spinous process of the 12th thoracic vertebrae, the 7th cervical vertebra, and the 8th thoracic vertebra; distal point of xiphoid process; and jugular notch), the humerus (medial and lateral epicondyles), and the scapula (the posterior lateral acromial angle, the root of the scapular spine, and the inferior angle of the scapula at the most inferior point of the scapula). The center

<table>
<thead>
<tr>
<th>Variable</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± SD), y</td>
<td>21.4 ± 2.3</td>
</tr>
<tr>
<td>Height (mean ± SD), cm</td>
<td>188.8 ± 5.0</td>
</tr>
<tr>
<td>Mass (mean ± SD), kg</td>
<td>89.8 ± 8.6</td>
</tr>
<tr>
<td>Arm dominance</td>
<td>9 left, 36 right</td>
</tr>
<tr>
<td>League for previous year</td>
<td>6 NCAA, 30 rookie/A, 9 AA, 3 AAA</td>
</tr>
<tr>
<td>Primary role</td>
<td>26 starters, 14 middle relief, 5 closers</td>
</tr>
</tbody>
</table>

Table 1 Participant Characteristics (N = 45)
of the humeral head was calculated by a least-squares algorithm while the humerus moved on the scapula in short arcs of less than 45°. These anatomical landmarks were selected based on recommendations of the International Society of Biomechanics Shoulder Group and have been used in previous studies. The landmarks were converted to anatomically defined local-coordinate axis systems derived from digitization for each segment. The orthogonal coordinate system for each segment was vertical (y-axis), horizontal to the right (x-axis), and posterior (z-axis). Position and orientation data were yielded after matrix transformations from the global to the local coordinate systems for each segment.

After the digitization process, participants were asked to remain standing with the palm of each hand flat against the lateral aspect of the thigh, eyes fixed forward, while the system calibrated a neutral position. Each participant then performed 5 trials of bilateral maximum forward flexion (elevation in the sagittal plane) to a verbal 3-second count, elbows in full extension and the thumbs pointing up, holding a 2.3-kg dumbbell in each hand, while electromagnetic data were collected (Figure 1). Before data collection, a series of 5 practice trials was performed to acquaint the participant with the flexion task, with verbal feedback from the investigators. This was repeated as necessary until the participant achieved the specified plane and velocity of elevation.

Data Reduction

3D coordinates of the digitized bony landmarks were calculated using Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL). Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics. Humeral motions were calculated as the Euler angles of the humerus relative to the thorax reference frame in the y-x′-y″ sequence in which the first rotation defined the plane of elevation about the y-axis, the second defined the amount of elevation about the x′-axis, and the third defined the amount of internal-external rotation about the y″-axis. Scapular rotations were calculated as the Euler angles of the scapula relative to the thorax reference frames in the y-x′-z″ order of rotations, with the first rotation defining internal/external rotation (IR/ER) about the y-axis, upward-downward rotation (UR/DR) about the x′ axis, and anteroposterior (AP) tilting about the z″-axis. Illustrations and descriptions of these scapular rotations have been previously published. Data were smoothed through a Butterworth low-pass digital filter (fourth-order, recursive, zero phase lag) at an estimated optimum cutoff frequency of 6.6 Hz.

Receiver data were used to calculate 3D scapular UR/DR, IR/ER, and AP tilt during 5 repetitions of weighted (2.3-kg) shoulder flexion. A correction equation was used to further reduce skin artifact with scapular UR. This was derived from linear functions using a least-squares fit of the scapular position determined with skin sensors based on bone-pin receivers in a validation study by Karduna et al. The formula applied was 

\[ e = \frac{a}{1 - a} U_s + \frac{\beta}{1 - a}, \]

where \( e \) is the difference between skin and bone receivers or error due to skin motion and \( U_s \) is error due to skin artifact with constants of \( a \) and \( \beta \) applied. Mean scapular angles were calculated from the continuous raw kinematic data at the humeral-elevation positions of rest, 30°, 60°, 90°, and 120° and maximum elevation for the middle 3 of 5 repetitions during the ascending movement phase of weighted shoulder flexion using MATLAB (version 7.6, R2008a, The MathWorks Inc, Natick, MA). The average scapular angles for these 3 trials were used for statistical analyses.

Statistical Analyses

Descriptive statistics were computed for all variables. Intertrial reliability using intraclass correlation coefficients (ICC2,1) as described by Shrout and Fleiss and error values were calculated for scapular kinematic variables. 3D scapular angles (UR/DR, IR/ER, and AP tilting) at specified humeral angles, both relative to the thorax, served as the dependent variables. The repeated factor was arm angle and the within subject variable was the side tested (throwing vs nonthrowing shoulder). Separate mixed-model repeated-measures ANOVAs (Side × Angle) were performed to compare each of the 3 scapular rotations between the throwing and the nonthrowing shoulder across humeral-flexion angles (rest, 30°, 60°, 90°, 120°).
90°, 120°, and maximum). For all comparisons, a level of $P < .05$ was considered statistically significant. With statistical significance, post hoc testing was performed with linear contrasts. The analyses of interest were main effects of side or interactions of side (throwing vs nonthrowing shoulder) and arm angle. All analyses were performed using SAS Software (JMP 8.1, SAS Institute Inc, Cary, NC).

**Results**

Scapular rotations in the throwing and nonthrowing shoulders are shown in Figures 2–4. As shown in Table 2, scapular UR/DR, IR/ER, and AP tilt displayed acceptable reliability, with ICC$_{2,1}$ values ranging from .87 to .97 and SEM values ranging from 1.9° to 3.2°. There were no statistically significant interactions between side and humeral-elevation angle for any of the scapular rotations. There were significant main effects of side for scapular UR/DR ($P < .001$), AP tilt ($P < .001$), and IR/ER ($P < .01$; Table 3). This showed that across all angles of elevation the throwing scapula displayed greater mean UR (increase = 3.6°, SE = 0.50°) and mean anterior tilt (increase = 2.1°, SE = 0.60°) but less mean IR (decrease = 2.1°, SE = 0.66°) than the nonthrowing shoulder across all arm angles.

**Discussion**

This is the first study to show resting alterations in the throwing shoulder’s 3D scapular orientation that are maintained throughout dynamic arm elevation compared with the nonthrowing shoulder in a large cohort (N = 45) of asymptomatic professional pitchers. The results of this study suggest scapular asymmetries in the shoulders of asymptomatic professional baseball pitchers with the throwing shoulder positioned from rest to maximum elevation in greater scapular UR and anterior tilt, but less IR. This offset in scapular position was found throughout a flexion task compared with the nonthrowing shoulder, but the pattern of scapular motion did not differ between throwing and nonthrowing shoulders. We suggest that the offset may be related to factors known to alter shoulder motion, including bony adaptations,$^{30,31}$ alterations in

![Figure 2](image2.png)

**Figure 2** — Mean (95% CI) scapular upward–downward rotation across arm angles in throwing and nonthrowing shoulders of 45 professional baseball pitchers.

![Figure 3](image3.png)

**Figure 3** — Mean (95% CI) scapular anteroposterior tilt across arm angles in throwing and nonthrowing shoulders of 45 professional baseball pitchers.
Scapular-muscle length, posterior shoulder tightness, or a combination of such factors not examined in this study.

Prior studies suggest that throwers demonstrate scapular asymmetry with the arms at rest and with static arm elevation. Using a digital inclinometer, Downar and Sauers found the throwing shoulder of professional baseball players (n = 20 pitchers, n = 7 position players) to be positioned in greater scapular UR (mean 4.1°) at 90° of abduction than the nonthrowing shoulder. However, only 1 aspect (UR) of 3D scapular position and orientation was examined, with the arm held in a static position. Oyama et al showed that the resting posture in the dominant shoulder of 43 overhead athletes had more anterior tilt (1.88°) and IR (3.8°) than the nondominant shoulder. While we found similar results with increased anterior tilt of the throwing shoulder (mean 2.1°) averaged across all arm angles, our results differed, showing greater scapular ER (mean 2.1°), not IR. This difference might be due to varying participant samples and the plane of motion examined. Oyama et al recruited a combination of baseball, tennis, and volleyball players and examined scapular position with the arm at rest. Downar and Sauers included not only pitchers but also position players and examined scapular position with elevation in the scapular plane. Our results are unique in that they specifically elucidate the side-to-side differences between the shoulders during continuous elevation.

Table 2 Intraclass Correlation Coefficients (ICC\textsubscript{2,1}) and Standard Error of the Measure (SEM) Values for Each Dependent Variable

<table>
<thead>
<tr>
<th>Scapular position and orientation</th>
<th>ICC\textsubscript{2,1}</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upward rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>throwing</td>
<td>.96</td>
<td>2.2°</td>
</tr>
<tr>
<td>nonthrowing</td>
<td>.97</td>
<td>1.9°</td>
</tr>
<tr>
<td>Internal rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>throwing</td>
<td>.92</td>
<td>3.2°</td>
</tr>
<tr>
<td>nonthrowing</td>
<td>.94</td>
<td>2.7°</td>
</tr>
<tr>
<td>Anteroposterior tilt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>throwing</td>
<td>.87</td>
<td>2.4°</td>
</tr>
<tr>
<td>nonthrowing</td>
<td>.91</td>
<td>2.1°</td>
</tr>
</tbody>
</table>

Table 3 Main-Effect Results of Scapular Orientation and Position in Throwing and Nonthrowing Shoulders Averaged Across Arm Angles in 45 Professional Baseball Pitchers

<table>
<thead>
<tr>
<th>Scapular position and orientation</th>
<th>Mean 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upward rotation</td>
<td></td>
</tr>
<tr>
<td>throwing</td>
<td>25.0° 22.9, 27.1</td>
</tr>
<tr>
<td>nonthrowing</td>
<td>21.4° 19.3, 23.5</td>
</tr>
<tr>
<td>difference</td>
<td>3.6°*** 2.7, 4.6</td>
</tr>
<tr>
<td>Internal rotation</td>
<td></td>
</tr>
<tr>
<td>throwing</td>
<td>27.9° 26.0, 32.1</td>
</tr>
<tr>
<td>nonthrowing</td>
<td>30.1° 28.0, 32.1</td>
</tr>
<tr>
<td>difference</td>
<td>–2.1°* –3.4, –0.8</td>
</tr>
<tr>
<td>Anteroposterior tilt</td>
<td></td>
</tr>
<tr>
<td>throwing</td>
<td>–7.7° –9.6, –5.8</td>
</tr>
<tr>
<td>nonthrowing</td>
<td>–5.6° –7.5, –3.7</td>
</tr>
<tr>
<td>difference</td>
<td>–2.1°** –3.2, –0.9</td>
</tr>
</tbody>
</table>

\*\( P < .01 \)  \*\*\( P < .001 \).
More recent research by Laudner et al\textsuperscript{11} suggests that pitchers have less scapular UR than position players do. However, a comparison of 3D shoulder kinematics between the throwing and nonthrowing shoulder was not performed. This is an important link to understanding potential movement alterations during a clinical examination. Thus, results of the study by Laudner et al cannot be directly compared with those of our study.

Decreased scapular posterior tilt and greater anterior tilt during active arm elevation found in the throwing shoulder in the current study are scapular alterations that are consistent with a shortened pectoralis minor in a study by Borstad and Ludewig.\textsuperscript{32} In pitchers, the pectoralis minor muscle may become adaptively shortened with the repetitive nature of forceful scapular IR and anterior tilt from the late cocking to ball-release phase of throwing.\textsuperscript{34} Furthermore, it has been suggested that a lack of scapular posterior tilt may contribute to outlet impingement by failing to move the anterior aspect of the acromion away from the humeral head during arm elevation.\textsuperscript{35,36} Scapular posterior tilt may also contribute to internal impingement by increasing hyperangulation of the humerus with the scapula in the late cocking phase.\textsuperscript{5} The pattern of greater scapular UR and ER with elevation, as found in this study, has been previously theorized to increase subacromial space as a potential compensatory protective mechanism to minimize outlet impingement,\textsuperscript{37} as well as lessen the risk of developing internal impingement by reducing hyperangulation of the humerus with the scapula in the late cocking phase of pitching.\textsuperscript{1,3} While all pitchers in this study were asymptomatic at the time of testing, it is unclear if the malpositioning of the throwing scapula in anterior tilt may contribute to development of injury over time. However, it is possible that any potential ill mechanical effects theorized to occur with increased anterior tilt in elite asymptomatic baseball pitchers may be offset by a gain in scapular UR and ER.

The results of this study suggest that a certain amount of scapular asymmetry (3–4°) throughout elevation may be normal in asymptomatic professional baseball pitchers. However, as illustrated in Figures 2 through 4, the throwing shoulder does not appear to move differently from the nonthrowing shoulder—a consistent offset in scapular UR, anterior tilt, and ER was maintained throughout the range of maximum elevation. This shift in scapular motion may be similar to the normal adaptation of internal and external glenohumeral range of motion commonly observed in overhead athletes.\textsuperscript{30,31,38,39} It is unclear if this asymmetry is a potential protective adaptation or is predictive of future pathology. Regardless, the results of this study should be considered when evaluating healthy professional baseball pitchers because an asymmetry or offset in motion consistently throughout elevation may not be as detrimental as previously hypothesized.

There are several limitations of this study to acknowledge. We included scapular position and orientation of both resting and maximum active humeral-elevation angles because these positions are frequently considered when comparing shoulders in a clinical examination. We recognize error in 3D scapular position and orientation related to skin artifact using surface receivers, particularly above 120° of humeral elevation; however, we employed a correction factor to reduce these effects in scapular UR. This error is systematic; it is an unlikely source for differences found between shoulders. Finally, we studied shoulder kinematics using a weighted (2.3-kg) flexion task as compared with scapular position and orientation with a throwing motion. This task more often identifies abnormal scapular motion, particularly in the sagittal plane, in those with shoulder injury,\textsuperscript{40} and bilateral arm elevation is used as a clinical method to examine scapular motion.\textsuperscript{36,40–42} Furthermore, it is unclear if the results of the current study can be extrapolated to other overhead sports such as tennis.

This is the only study demonstrating that 3D scapular alterations of the throwing shoulder in professional pitchers occur primarily across active arm-elevation angles from rest to full elevation. This is important because comparison of scapular motion between shoulders is used in the clinical examination of overhead athletes.\textsuperscript{1,17} Increased scapular UR, ER, and anterior tilt in resting posture that are maintained throughout elevation may be related to chronic adaptations of the dominant shoulder due to the demands of throwing in asymptomatic professional pitchers. Although we theorize that the findings of this study are related to potentially normal adaptations, further study is necessary to determine whether these adaptations may contribute to development of pathology or serve as a compensation to avoid injury.

**Conclusions**

Asymptomatic professional baseball pitchers present with alterations in scapular orientation of the throwing shoulder throughout elevation compared with the nonthrowing shoulder, but not in the pattern of scapular motion. Based on the results of this study, we theorize that scapular asymmetry with a consistent offset between shoulders may be a normal adaptation in professional baseball pitchers and may not necessarily indicate pathology; however, longitudinal study is necessary to determine if alterations in 3D scapular kinematics of the throwing shoulder found at rest in asymptomatic pitchers are protective or harmful.

**Acknowledgments**

Funding for this study was provided by the Foundation for Physical Therapy, the Orthopedic Research Foundation of the Carolinas, and the University of North Florida Brooks Rehabilitation Foundation.

**References**

2. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy


