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Comparison of 3-Dimensional Shoulder Complex Kinematics in Individuals With and Without Shoulder Pain, Part 1: Sternoclavicular, Acromioclavicular, and Scapulothoracic Joints

STUDY DESIGN: Cross-sectional.

OBJECTIVES: To compare sternoclavicular, acromioclavicular, and scapulothoracic joint motion between symptomatic and asymptomatic individuals during shoulder motion performed in 3 planes of humerothoracic elevation.

BACKGROUND: Differences in scapulothoracic kinematics are associated with shoulder pain. Several studies have measured these differences using surface sensors, but the results of this technique may be affected by skin-motion artifact. Furthermore, previous studies have not included the simultaneous measurement of sternoclavicular and acromioclavicular joint motion.

METHODS: Transcortical bone pins were inserted into the clavicle, scapula, and humerus of 12 asymptomatic and 10 symptomatic individuals for direct, bone-fixed tracking using electromagnetic sensors. Angular positions for the sternoclavicular, acromioclavicular, and scapulothoracic joints were measured during shoulder flexion, abduction, and scapular plane abduction.

RESULTS: Differences between groups were found for sternoclavicular and scapulothoracic joint positions. Symptomatic individuals consistently demonstrated less sternoclavicular posterior rotation, regardless of angle, phase, or plane of shoulder motion. Symptomatic individuals also demonstrated less scapulothoracic upward rotation at 30° and 60° of humerothoracic elevation during shoulder abduction and scapular plane abduction.

CONCLUSION: The results of this study show that differences in shoulder complex kinematics exist between symptomatic and asymptomatic individuals. However, the magnitude of these differences was small, and the resulting clinical implications are not yet fully understood. The biomechanical coupling of the sternoclavicular and acromioclavicular joints requires further research to better understand scapulothoracic movement deviations and to improve manual therapy and exercise-based physical therapy interventions. *J Orthop Sports Phys Ther 2014;44(9):636-645. Epub 7 August 2014. doi:10.2519/jospt.2014.5339*

KEY WORDS: *biomechanics, clavicle, impingement syndrome, scapula, transcortical bone pins*

Shoulder pain is the second most common musculoskeletal complaint, with a reported point prevalence of 20.9% in the general population.[29] The majority of patients presenting with shoulder pain to a physician are given a diagnosis of "impingement."[34] Subacromial impingement has long been proposed as a mechanism of shoulder pain and is described as the repeated compression of the bursal side of the rotator cuff tendons with the undersurface of the acromion.[27] Internal impingement has also been proposed as a mechanism for shoulder pain, which occurs when the undersurface of the rotator cuff becomes entrapped by the posterosuperior rim of the glenoid.[35]

While pathoanatomical theories of these diagnostic labels are common in the literature,[2,25,35] the actual pathomechanics are not well understood. Previous

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TABLE 1 DEMOGRAPHIC DATA*

Characteristic	Asymptomatic (n = 12)	Symptomatic (n = 10)	*P* Value
Age, y	29.3 ± 6.8	35.7 ± 13.4	.165
Gender (male), n	7	5	1.000
Height, cm	173.6 ± 8.1	170.3 ± 10.7	.438
Mass, kg	77.5 ± 13.8	78.6 ± 11.3	.842
BMI, kg/m^2	25.7 ± 4.3	27.3 ± 4.5	.418
Handedness (right), n	11	10	1.000
Dominant side tested, n	2	8	.008
DASH (0-100)	...	21.4 ± 10.8	...
Optional work module (0-100)	...	20.3 ± 22.3	...
Optional sports module (0-100)	...	49.2 ± 27.0	...
Symptom duration, y	...	10.0 ± 7.9	...
NPRS (usual shoulder joint symptoms) (0-10)	...	2.7 ± 1.7	...
NPRS during testing (at bone pin sites) (0-10)	1.9 ± 0.9	2.6 ± 2.1	.104

Abbreviations: BMI, body mass index; DASH, Disabilities of the Arm, Shoulder and Hand questionnaire; NPRS, numeric pain rating scale.
**Values are mean ± SD unless otherwise indicated.*

studies have found differences in scapulothoracic motion between symptomatic and asymptomatic individuals.[5,10,17,21,23] However, both the magnitude and direction of group differences often vary between studies. This is likely due to methodological considerations and differences in sample populations, and may reflect the broad nature of impingement as a diagnostic label.[1] Furthermore, these comparisons are confounded by the skin-motion artifact associated with the use of surface electromagnetic sensors,[8,13] making the observed group differences difficult to interpret.

During shoulder elevation, substantial motion also occurs at the sternoclavicular and acromioclavicular joints,[20,24] contributing to scapulothoracic motion through mechanical coupling.[3,11,33] Therefore, abnormal sternoclavicular and acromioclavicular motion is expected to occur with abnormal scapulothoracic motion. While several studies have estimated sternoclavicular joint positions using various methodological assumptions,[15,21,23] no study has measured sternoclavicular and acromioclavicular joint kinematics in symptomatic individuals by directly tracking clavicular motion.

The purpose of this study was to compare differences in sternoclavicular, acromioclavicular, and scapulothoracic motion between symptomatic and asymptomatic individuals during shoulder motion performed in 3 planes of humerothoracic elevation. In combination with a companion article,[16] the results of this study allow for a comprehensive investigation into shoulder kinematics associated with shoulder pain and the diagnostic label of impingement. The use of simultaneous tracking of bone-fixed sensors allowed for highly accurate assessment of motion and further investigation into the biomechanical relationships between the joints of the shoulder complex.

METHODS

Participants

TWENTY-FOUR PARTICIPANTS (12 asymptomatic, 12 symptomatic) were recruited from a university setting and the local metropolitan area to participate in this study. Data from 2 symptomatic participants were not included in the analysis. One participant was found to have end-stage glenohumeral joint osteoarthritis following a computerized tomography scan for another study. Data from another symptomatic participant were excluded due to loosening of the scapular bone pin. Additionally, 1 asymptomatic participant had movement of the clavicular pin during testing. Therefore, the sample size for the symptomatic group was reduced to 10 for all analyses, and the asymptomatic group was reduced to 11 for sternoclavicular and acromioclavicular analyses. The study protocol was approved by the Institutional Review Board of the University of Minnesota, and written informed consent was obtained from all participants prior to testing. Demographic data of the participants are presented in **TABLE 1**.

The inclusion/exclusion criteria for the symptomatic participants were intended to include a sample of individuals with a clinical presentation consistent with impingement syndrome[26,28] and to exclude those with adhesive capsulitis, primary cervical referred pain, or other common shoulder conditions. Specifically, the inclusion criteria for the symptomatic group were (1) 18 to 60 years of age, (2) current anterolateral shoulder pain of at least 1 week in duration, (3) pain during active shoulder motion, (4) pain provocation with resisted shoulder internal or external rotation, (5) visible scapular dyskinesis during active arm raising or lowering, and (6) at least 2 positive impingement tests (Hawkins-Kennedy, Neer, Jobe).[9,12,27] Exclusion criteria for the symptomatic group were[17] (1) 25% or greater reduction in glenohumeral internal or external rotation range of motion compared to the contralateral side[30]; (2) symptom onset following trauma; (3) symptom reproduction during a cervical spine screening; (4) positive drop-arm or apprehension test; (5) history of shoulder surgery, labral tear, or rotator cuff tear; (6) previous fracture of the clavicle, scapula, or humerus; and (7) known joint disease (eg, rheumatoid arthritis or osteoarthritis).

The inclusion criteria for the asymptomatic group were (1) 18 to 60 years of age, and (2) pain-free shoulder range of

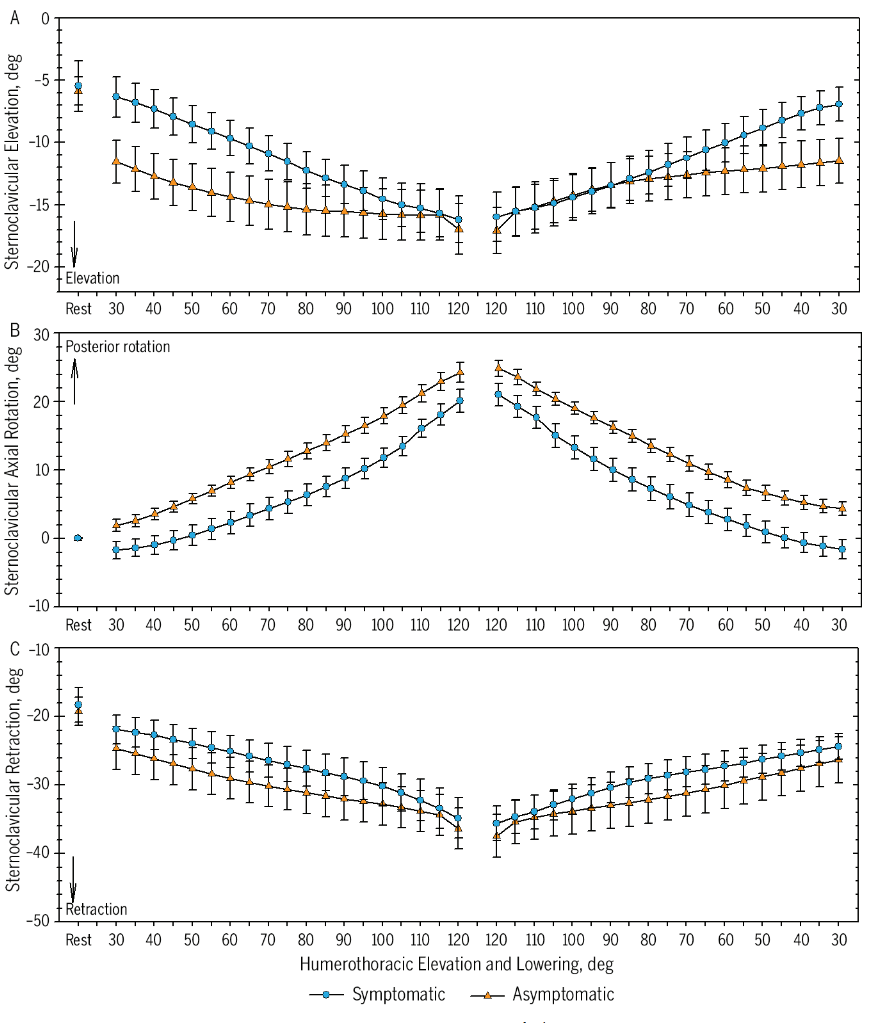

FIGURE 1. Sternoclavicular joint motion during shoulder scapular plane abduction: (A) elevation/depression, (B) axial rotation, (C) protraction/retraction. The symptomatic group had less elevation at 30° arm raising and less posterior rotation throughout the range of motion. Values are mean and unpooled standard error in degrees.

motion. Potential participants were excluded from the asymptomatic group if they had (1) a history of shoulder pain; (2) a history of fracture of the clavicle, scapula, or humerus; (3) a history of dislocation or separation of any shoulder complex joint; (4) any abnormal or asymmetrical loss of shoulder range of motion; (5) provocation of pain during special tests for impingement; and (6) visible scapular dyskinesia during motion assessment.

Procedures

Data collected on both groups were part of a more comprehensive investigation that included other variables and movements. Kinematic data from the asymptomatic group were included in a previous manuscript.[20] Electromagnetic sensors for kinematic tracking were rigidly fixed to transcortical bone pins inserted into the lateral third of the clavicle, the base of the scapular acromion, and just distal to the deltoid tuberosity on the lateral humerus, as previously described (**APPENDIX FIGURE 1**, available online).[20] Kinematic data were collected using the Flock of Birds miniBIRD electromagnetic system (Ascension Technology Corporation, Shelburne, VT) and MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL). The sampling rate of the system was 100 Hz per sensor, with a reported static accuracy of 0.5° and 1.8 mm within a 76.2-cm range (Ascension Technology Corporation). The static position accuracy of the system was verified in our lab by digitizing a calibration grid using a sensor attached to a stylus with a known tip offset. The calculated root-mean-square error was less than 1 mm.

Local coordinate systems were constructed by palpating and digitizing anatomical landmarks according to the recommendations of the International Society of Biomechanics.[36] For the scapular coordinate system, the posterior aspect of the acromioclavicular joint was used instead of the posterolateral acromion to describe scapular motion in a more clinically meaningful manner.[19] Motions of the clavicle, scapula, and humerus were described using Cardan and Euler angles, according to published recommendations.[36] Sternoclavicular joint motion described movement of the clavicle relative to the trunk as protraction/retraction, elevation/depression, and axial rotation (*yx'z"*). Acromioclavicular joint motion described movement of the scapula relative to the clavicle as internal/external rotation, upward/downward rotation, and anterior/posterior tilting (*yx'z"*). Scapulothoracic joint motion described movement of the scapula relative to the thorax as internal/external rotation, upward/downward rotation, and anterior/posterior tilting (*yx'z"*). Humerothoracic motion described movement of the humerus relative to the trunk in the order of plane of elevation, humeral elevation, and axial rotation (*yx'y"*).

Motion testing consisted of 2 repetitions each of shoulder abduction, flexion, and scapular plane abduction, which was defined as 40° anterior to the coronal plane.[20,24] The plane of movement was verified prior to testing using software and controlled during movement using a vertical planar surface. Participants were instructed to move at a rate of 3 seconds for each phase of raising and lowering. The integrity of the placement of the bone pins and sensors was monitored throughout testing.

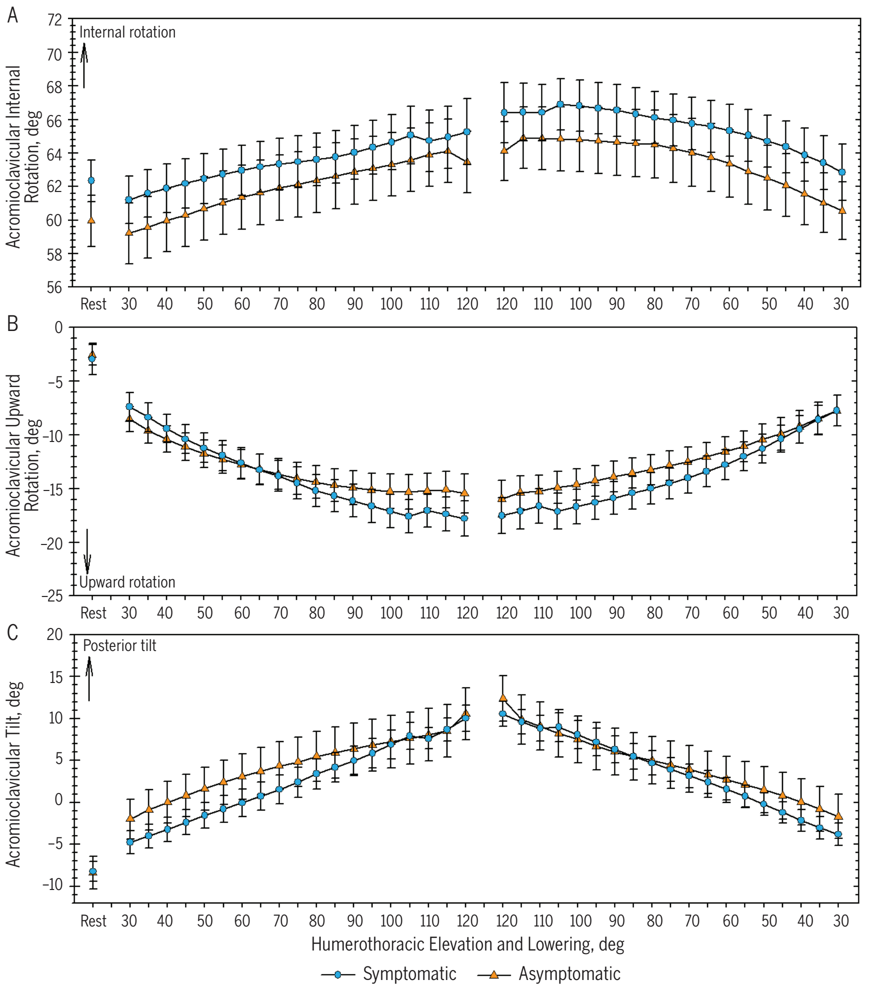

FIGURE 2. Acromioclavicular joint motion during shoulder scapular plane abduction: (A) internal/external rotation, (B) upward/downward rotation, (C) anterior/posterior tilting. Values are mean and unpooled standard error in degrees.

Kinematic data for each participant's relaxed standing posture and motion assessment were exported from the MotionMonitor software, and motion data were reduced to 5° increments. Data from all planes of motion were plotted from 30° to 120° of humerothoracic elevation (**FIGURES 1-3**; **APPENDIX FIGURES 2-7**, available online). Data were not presented or analyzed below 30° of humerothoracic elevation because the trunk prevents a true 0° position and data from an insufficient number of participants were available to produce a mean value that was representative.

Statistical Analysis

Trial-to-trial reliability was tested using intraclass correlation coefficients ($ICC_{1,1}$) by performing a 1-factor analysis of variance with participants as the independent variable.[32] This analysis was performed for each dependent variable and movement condition. Intraclass correlation coefficients were only calculated in the presence of significant participant main effects to ensure validity of the statistic.[14] Standard error of measurement values were calculated as the square root of the within-subject error term.[6] After establishing reliability, the 2 repetitions for each participant were averaged for each dependent variable over angles of humerothoracic elevation and phases of motion, and these values were utilized for statistical analysis.

Prior to analysis, the assumption of normality was tested by assessing skewness and kurtosis. The primary statistical analysis consisted of 3-factor, mixed-model analyses of variance. The between-subject factor was group (asymptomatic, symptomatic) and the within-subject factors were phase (raising, lowering) and angle of humerothoracic elevation. For shoulder flexion and scapular plane abduction, comparisons were made at 30°, 60°, 90°, and 120° of humerothoracic elevation. However, because several participants in the symptomatic group did not achieve 120° of humerothoracic elevation during shoulder abduction, comparisons were made at 30°, 60°, 90°, and 110° of humerothoracic elevation in this plane. Separate analyses were conducted for each dependent variable in each plane of shoulder movement (abduction, flexion, and scapular plane abduction).

For the mixed models, 3-factor interactions were first assessed. If a significant interaction was found, contrast statements were used to compare groups at each level of angle within each level of phase; if a significant interaction was not found, 2-factor interactions between groups were assessed. The significance of main effects was only identified in the absence of interactions involving that factor. Baseline demographic data were compared using 2-sample *t* tests for continuous data. Due to small expected counts, the Fisher exact test was used for comparing proportions. Two-sample *t* tests were also performed to compare angular positions between groups with the arm relaxed at the side. The acceptable type I error rate was set a priori at .05. Tukey-Kramer adjustments for multiple comparisons were used for the mixed models when appropriate. All statistical analyses were performed using SAS Version 9.3 (SAS Institute Inc, Cary, NC).

RESULTS

The average ICC values for each dependent variable ranged from 0.83 to 0.98 for the asymptomatic group and 0.76 to 0.96 for the symptomatic group (**APPENDIX TABLE 1**, available online). Estimates of within-subject trial-to-trial variability (standard error of measurement) were generally less than 2° in both groups. The normality of the data was found to be within an acceptable range. No differences were found between groups in sternoclavicular, acromioclavicular, scapulothoracic, or humerothoracic joint positions in a relaxed standing position (**TABLE 2**).

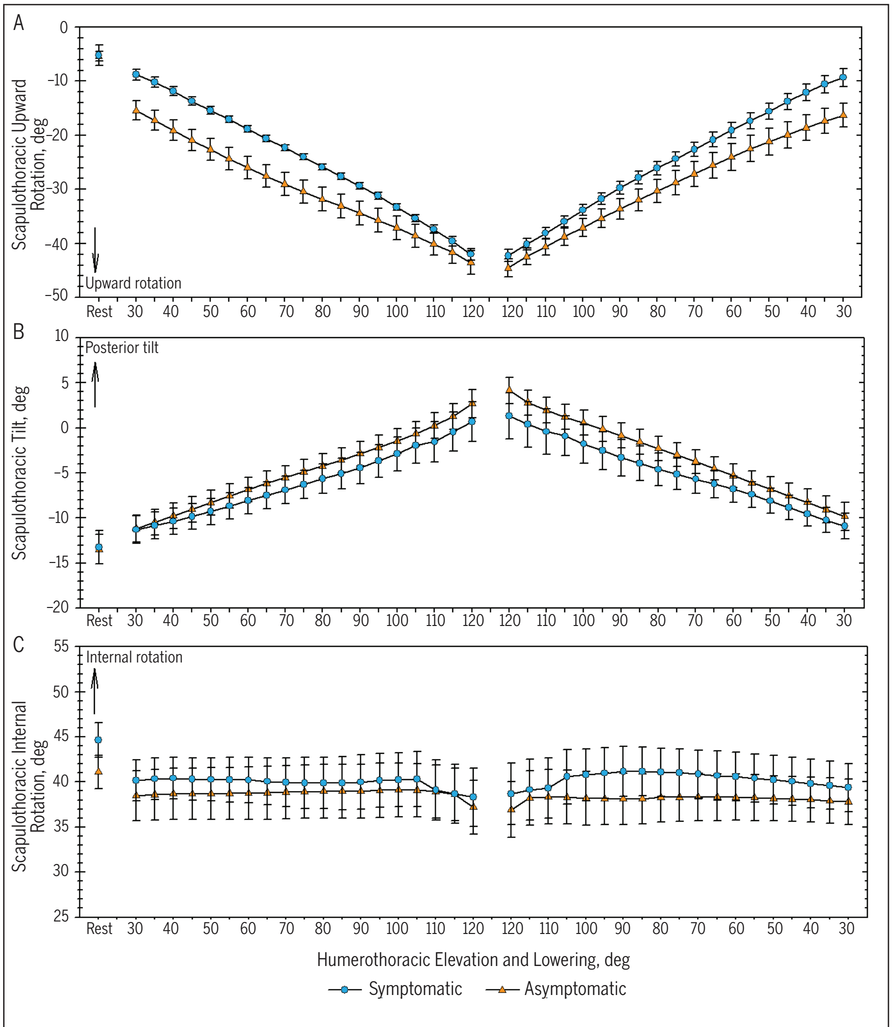

FIGURE 3. Scapulothoracic motion during shoulder scapular plane abduction: (A) upward/downward rotation, (B) anterior/posterior tilt, (C) internal/external rotation. The symptomatic group had less upward rotation at 30° and 60° of humerothoracic elevation, regardless of phase. Values are mean and unpooled standard error in degrees.

Sternoclavicular Joint

During humerothoracic elevation, both the symptomatic and asymptomatic groups demonstrated similar patterns of progressive sternoclavicular elevation (**FIGURE 1A**; **APPENDIX FIGURES 2A** and **5A**, available online). However, differences between groups existed for scapular plane abduction and were dependent on the angle of elevation and the phase of motion ($P<.001$, F = 7.32, *df* = 3,55). The only significant difference between groups in pairwise comparisons occurred at 30° of humerothoracic elevation during arm raising, when the symptomatic group had 5.2° less sternoclavicular elevation ($P = .046$, F = 4.18, *df* = 1,55).

Both groups demonstrated a pattern of progressive sternoclavicular posterior rotation during humerothoracic elevation (**FIGURE 1B**; **APPENDIX FIGURES 2B** and **5B**, available online). Differences between groups were consistent across all angles of elevation and phases of motion. On average, the symptomatic group had 5.2° less posterior rotation during abduction ($P = .009$, F = 8.55, *df* = 1,19) (**APPENDIX FIGURE 5B**, available online), 5.9° less posterior rotation during flexion ($P = .003$, F = 12.15, *df* = 1,19) (**APPENDIX FIGURE 2B**, available online), and 5.5° less posterior rotation during scapular plane abduction ($P = .002$, F = 13.30, *df* = 1,19) (**FIGURE 1B**). Progressive sternoclavicular retraction was also observed in both groups, without significant differences between groups or interactions with group (**FIGURE 1C**; **APPENDIX FIGURES 2C** and **5C**, available online).

Acromioclavicular Joint

During humerothoracic elevation in all 3 planes of motion, both groups demonstrated progressive acromioclavicular internal rotation (**FIGURE 2A**; **APPENDIX FIGURES 3A** and **6A**, available online), upward rotation (**FIGURE 2B**; **APPENDIX FIGURES 3B** and **6B**, available online), and posterior tilt (**FIGURE 2C**; **APPENDIX FIGURES 3C** and **6C**, available online). Group differences for tilt during scapular plane abduction depended on the angle of elevation and the phase of motion ($P = .027$, F = 3.30, *df* = 3,55) (**FIGURE 2C**). However, subsequent pairwise follow-up tests did not find significant differences between groups. Group differences were not observed for acromioclavicular internal rotation or upward rotation.

Scapulothoracic Joint

During humerothoracic elevation, both groups demonstrated progressive scapulothoracic upward rotation with increasing angles of humerothoracic elevation (**FIGURE 3A**; **APPENDIX FIGURES 4A** and **7A**,

TABLE 2 Angular Positions in Relaxed Standing Posture

	Asymptomatic*	Symptomatic*	*P* Value
Sternoclavicular joint			
Retraction	19.2 ± 2.1	18.3 ± 2.5	.792
Elevation	5.9 ± 1.1	5.5 ± 2.1	.861
Posterior rotation	0.1 ± 0.1	0.1 ± 0.1	.997
Acromioclavicular joint			
Internal rotation	60.0 ± 1.5	62.3 ± 1.2	.249
Upward rotation	2.5 ± 1.0	2.9 ± 1.4	.812
Anterior tilt	8.4 ± 2.0	8.2 ± 1.2	.950
Scapulothoracic joint			
Internal rotation	41.1 ± 1.8	44.6 ± 1.9	.198
Upward rotation	5.4 ± 0.9	5.2 ± 1.9	.915
Anterior tilt	13.5 ± 1.6	13.2 ± 1.8	.921
Humerothoracic			
Elevation	11.0 ± 1.0	15.0 ± 1.8	.056

**Values are mean ± standard error in degrees.*

available online), and differences between groups were found at lower angles of abduction (P = .034, F = 3.10, df = 3,58) and scapular plane abduction (P = .009, F = 4.27, df = 3,58). During abduction, the symptomatic group demonstrated 6.5° less upward rotation at 60° of arm raising (P = .007, F = 7.97, df = 1,58) and 6.3° less upward rotation at 30° of arm lowering (P = .008, F = 7.60, df = 1,58) (**APPENDIX FIGURE 7A**, available online). When humerothoracic elevation was performed in the scapular plane, the symptomatic group demonstrated 6.8° less upward rotation at 30° (P = .005, F = 8.52, df = 1,58) and 3.1° less upward rotation at 60° (P = .012, F = 6.69, df = 1,58) (**FIGURE 3A**).

For scapulothoracic tilt, both groups demonstrated progressive posterior tilt during arm raising (**FIGURE 3B**; **APPENDIX FIGURES 4B** and **7B**, available online). Group differences during flexion were found to depend on the angle of elevation (P = .016, F = 3.75, df = 3,57) (**APPENDIX FIGURE 4B**, available online). However, subsequent pairwise follow-up tests did not find significant group differences. Finally, the extent to which the scapula internally or externally rotated on the thorax was highly variable between participants, and significant differences between groups were not observed (**FIGURE 3C**; **APPENDIX FIGURES 4C** and **7C**, available online).

DISCUSSION

THE PRIMARY FINDINGS OF THIS study were that participants with a diagnosis of shoulder impingement demonstrated significantly reduced scapulothoracic upward rotation at lower angles of humerothoracic elevation and significantly reduced sternoclavicular posterior rotation throughout humerothoracic elevation. Additionally, symptomatic participants were in less sternoclavicular elevation at lower angles of scapular plane abduction. Importantly, the magnitude of each observed group difference was at least twice the standard error of measurement, indicating that measurement error alone cannot account for these findings.

To our knowledge, this is the first study to directly measure and compare sternoclavicular and acromioclavicular joint positions between symptomatic and asymptomatic populations. Interestingly, sternoclavicular posterior rotation was consistently decreased in the symptomatic group regardless of angle, phase, or plane of humerothoracic elevation. Given that no muscle has been shown to directly produce sternoclavicular axial rotation, this motion is believed to occur as the result of scapular upward rotation, which produces sternoclavicular joint motion through tension in the acromioclavicular and coracoclavicular ligaments.[3] As such, the finding of decreased sternoclavicular posterior rotation serves as an important biomechanical marker of scapulothoracic upward rotation and potential mechanisms for differences between groups. Currently, there are no clinically described measures for the assessment of sternoclavicular axial rotation, and further research is needed. Visual assessment may be a consideration in patients who are at risk for reduced axial rotation, such as those with a history of acromioclavicular joint instability.

In addition to comparing kinematics, the design of the present study allows for an in-depth investigation of how differences between groups relate across the joints of the shoulder complex. This relationship between scapulothoracic, sternoclavicular, and acromioclavicular joint motion has been termed *coupling*[3,33] and proposes that abnormal sternoclavicular or acromioclavicular joint motion may lead to and/or result from abnormal scapulothoracic motion. Consequently, the coupling theory is crucial to develop biomechanical theories for explaining pathology and potential causative or compensatory movement patterns. However, the mechanisms of these interactions are not well understood. Clinically, the coupling theory can be useful for physical therapists to develop movement-based examination and intervention strategies by considering how the sternoclavicular and acromioclavicular joints contribute to or result from abnormal scapulothoracic motion. This biomechanical paradigm may also contribute to the development of movement-based classification systems for diagnosing shoulder pain.

In the current study, group differences were consistently found between component motions coupled with scapulothoracic upward rotation. Therefore, the focus of the findings of this study is the coupling theory relative to scapulothoracic upward rotation, which is produced by the coupling of sternoclavicular posterior rotation and elevation, and acromioclavicular upward rotation.[33]

During shoulder scapular plane abduction, the symptomatic group showed reduced scapulothoracic upward rotation at 30° and 60° of humerothoracic elevation as compared to the asymptomatic group. A similar difference between groups was found during shoulder abduction at 30° of humerothoracic elevation during arm raising. According to the coupling theory, one would also expect to find reductions in some or multiple component motions, including sternoclavicular posterior rotation, sternoclavicular elevation, and/or acromioclavicular upward rotation. In both planes of humeral elevation, reduced sternoclavicular posterior rotation in the symptomatic group throughout the range of motion supports this theory. Furthermore, during shoulder scapular plane abduction, the symptomatic group also showed decreased sternoclavicular elevation at 30° during arm raising.

These differences between groups in joint positions are helpful in relating findings to conditions such as mechanical impingement. Previous studies have reported that the rotator cuff tendons are located between the undersurface of the acromion and the humeral head between 34° and 72° of scapular plane abduction.[7] In the present study, the 7° difference between groups in upward rotation occurred in this range of impingement risk. However, the magnitude of the difference between groups was small, and the impacts on the mechanisms of impingement have yet to be established. While causality cannot be assumed with respect to these findings, the findings do support a potential movement-related mechanism for symptoms related to mechanical impingement.

While joint positions may help relate findings to pathology, estimates of changes in joint angular position (biomechanically defined as angular displacement) better reflect magnitudes of movement. Although these comparisons were not assessed statistically, they are important to consider for clinicians to relate our findings to movement-based impairments. During the interval from rest to 30° of scapular plane abduction, the asymptomatic group had approximately 10° of scapulothoracic upward rotation displacement, whereas the symptomatic group only demonstrated 4°. By 90° of humerothoracic elevation, the difference between groups in scapulothoracic upward rotation position observed at both 30° and 60° no longer existed. For this to occur, the symptomatic group must have demonstrated increased scapulothoracic upward rotation displacement beyond 60° of humerothoracic elevation. Estimates of displacement support this theory, with the symptomatic group demonstrating 2° more scapulothoracic upward rotation than the asymptomatic group between 60° and 90°, and 3° more upward rotation between 90° and 120°.

The mechanisms by which the symptomatic group caught up to the asymptomatic group in terms of scapulothoracic upward rotation can be described within the context of the coupling theory. First, sternoclavicular elevation contributes a small amount to scapulothoracic upward rotation through coupling.[33] Between 60° and 90° of humerothoracic elevation, the symptomatic group had approximately 3° more sternoclavicular elevation displacement than the asymptomatic group. Similarly, between 90° and 120°, the symptomatic group had 2° more sternoclavicular elevation displacement. Both intervals of increased sternoclavicular elevation displacement in the symptomatic group likely helped to reduce the differences in scapulothoracic upward rotation between the groups at higher angles of humerothoracic elevation. Although muscle activation was not measured, the biomechanical data suggest initial reduced activation of the upper trapezius early in the motion, followed by increased activation as the upward rotation "normalized" through increased sternoclavicular elevation. Such a theory should be further investigated and, if supported, would help to guide a targeted exercise intervention.

Second, while the groups were similar in acromioclavicular upward rotation across all angles of elevation, the slope of the line for the symptomatic group was descriptively increased beyond 90° of humerothoracic elevation compared to the asymptomatic group (**FIGURE 2B**). Although differences in joint position were not statistically significant, this suggests more acromioclavicular upward rotation displacement in the symptomatic group during this range of motion, which might have further reduced the group differences in scapulothoracic upward rotation.

Finally, following an initial period of sternoclavicular anterior rotation as compared to a resting standing posture, the symptomatic group remained in less posterior rotation throughout the range of motion (**FIGURE 1B**). This group difference is likely the result of the reduction in scapulothoracic upward rotation in the same range, because sternoclavicular posterior rotation is presumably a byproduct of scapulothoracic upward rotation through tension in the acromioclavicular and coracoclavicular ligaments.[3] However, given that the group difference in scapulothoracic upward rotation resolved by 90°, the continued reduction in sternoclavicular posterior rotation in the symptomatic group beyond 90° may be related to another factor. For example, laxity in the coracoclavicular and/or acromioclavicular joint ligaments, resulting in reduced transference of scapular motion to the clavicle, may represent a mechanism to account for this difference. Alternatively, tightness in the upper trapezius and/or pectoralis major clavicular head might have restricted sternoclavicular posterior rotation, resulting in the observed pattern.

An important consideration when proposing these biomechanical theories to explain group differences is the variability of the data. Shoulder kinematics are often found to be highly variable among asymptomatic individuals,[20,24,31] and often mean values may not actually represent the "typical" pattern of motion. For example, though it is often reported that the scapula externally rotates on the thorax during humeral elevation,[4,18,20,22-24] our data suggest that only 17% to 40% of individuals demonstrate this pattern, depending on the plane of motion (**APPENDIX TABLE 4**, available online). The remaining participants consistently internally rotated, demonstrated a combination of internal and external rotation, or showed little change in scapular position about this axis. Therefore, it is important to consider the unpooled standard errors (**FIGURES 1-3**; **APPENDIX FIGURES 2-7**, available online) and the subject-specific patterns of motion (**APPENDIX TABLES 2-4**, available online) when interpreting the outcomes of kinematic studies.

The variability of shoulder kinematic data in patients with impingement and the inconsistency of group differences reported between studies suggest that a variety of movement impairments likely occur within this patient population. Furthermore, there is an increasing awareness that the impingement diagnosis is very broad and multifactorial and may actually consist of several subgroups of patients with different patterns of movement or even different pathoanatomical diagnoses.[1] Consequently, this study sample may not represent all the possible movement deviations that contribute to rotator cuff impingement. Also, the magnitude at which movement deviations actually contribute to rotator cuff mechanical compression or entrapment is not yet clear. Ultimately, more research is needed to better understand the relationship between shoulder pathology and related movement-based impairments, as it is likely that subgroups of patients with different movement impairments would benefit from specifically targeted exercise interventions.

This study has limitations that should be considered. First, the study's small sample size and between-subject variability limit the statistical power to detect group differences. This limitation was observed in significant interactions that were not always detectable in specific follow-up comparisons between groups. Furthermore, among the analyses that did not reach statistical significance, the mean differences between groups were generally less than 4°, and the clinical impact of a difference this small is doubtful, even if statistically significant. However, the nonsignificant 6° group difference observed for sternoclavicular retraction during shoulder flexion warranted a post hoc power analysis. Using a 5° difference, thought to represent a clinically meaningful difference, and the variance found in the present study, a 32% power was detected. This low power indicates a high probability of a type II error and is likely due to the high between-subject variability associated with the motion.

Second, the participants in the symptomatic group had a chronic history of intermittent shoulder pain (mean, 10 years since initial onset). Movement patterns in patient populations with acute pain may be substantially different. Furthermore, because the presence of dyskinesia was an inclusion criterion, the results of this study may not relate to patients presenting without visible movement impairments.

Third, pain caused by the bone pin might have altered the participants' natural motion. The average pain (numeric pain rating scale) at the site of the bone pins during movement was 1.9/10 for the asymptomatic group and 2.6/10 for the symptomatic group. While not statistically different between groups (**TABLE 1**), it is possible that the motion observed was influenced by the presence of pain in both groups. However, it is important to consider that the pain from the pin insertion does not likely simulate typical shoulder joint symptoms.

Fourth, the dominance of the side used for kinematic testing is a potential covariate in the analysis, given that the dominant side was used for testing in 2 of 12 asymptomatic participants and the dominant/symptomatic side was used in 8 of 10 symptomatic participants. Only 2 asymptomatic participants were tested on their dominant side due to the invasive nature of the study and because, at the initiation of this study, there were no data supporting side-to-side differences in shoulder kinematics. A subsequent study reported average scapular upward rotation to be approximately 5° less on the dominant side as compared to the nondominant side, using a within-subject design.[22] However, dominance does not likely explain this between-group difference, as the trend of decreased upward rotation on the dominant side was not observed in the present study. A descriptive comparison showed that the subset of participants tested on their dominant side had increased upward rotation within the same group as compared to those tested on the nondominant side. Furthermore, an exploratory analysis of covariance adjusting for dominance of the side tested increased rather than decreased the between-group differences in scapulothoracic upward rotation.

Finally, although the groups were not significantly different in age, participants in the symptomatic group were, on average, 6 years older than the asymptomatic participants. Therefore, it is possible that group differences were influenced by age. However, it is unlikely that this small age difference would account for the differences observed between groups, especially considering that no study has directly investigated the effects of small age differences on shoulder kinematics.

While the results of this study are most easily viewed from a biomechanical perspective, the clinical implications should not be overlooked. The observed kinematic variability within the symptomatic group reflects the wide variability of movement impairments within the diagnosis of impingement syndrome and the broad use of the diagnostic label in general. Despite this variability, consistent differences were observed between groups. In particular, scapulothoracic upward rotation and sternoclavicular posterior rotation and elevation were reduced in the symptomatic group. While sternoclavicular axial rotation is difficult to observe clinically, it is likely related to a concurrent reduction in scapulothoracic upward rotation. Therefore, assessment of abnormal scapulothoracic upward rotation may serve as an important component of a movement-based clinical examination for patients with shoulder pain. Clinicians should also consider the coupled mechanics between the sternoclavicular and acromioclavicular joints when observing scapulothoracic motion to more comprehensively examine shoulder movement patterns and plan intervention strategies.

CONCLUSION

Differences in shoulder girdle kinematics exist between symptomatic and asymptomatic individuals. The magnitudes of differences are small and the resulting clinical implications are not yet understood. However, the differences observed clearly exceeded the magnitude of the measurement error. The biomechanical coupling of the sternoclavicular and acromioclavicular joints in producing scapulothoracic motion requires further research to better understand scapular movement deviations and improve targeted manual therapy and exercise-based physical therapy interventions.

KEY POINTS

FINDINGS: Group differences were found for scapular upward rotation at early angles of humerothoracic elevation and in sternoclavicular posterior rotation throughout all angles and phases.

IMPLICATIONS: Changes in sternoclavicular and/or acromioclavicular joint motion occur with abnormal scapulothoracic motion and should be considered during the movement assessment of a clinical examination.

CAUTION: This study was limited by a small sample size. The diagnostic label of impingement is very broad and multifactorial, which may result in subgroups of patients with different patterns of movement.

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APPENDIX

TABLE 1 Intraclass Correlation Coefficients for Trial-to-Trial Reliability*

	Asymptomatic			Symptomatic		
	Abduction	**Flexion**	**SAB**	**Abduction**	**Flexion**	**SAB**
Sternoclavicular joint positions						
Protraction/retraction	0.97 (1.3)	0.98 (1.6)	0.98 (1.4)	0.93 (1.7)	0.90 (1.9)	0.93 (1.8)
Elevation/depression	0.96 (1.1)	0.97 (1.0)	0.97 (1.1)	0.93 (1.3)	0.93 (1.4)	0.93 (1.2)
Axial rotation	0.83 (1.7)	0.90 (1.1)	0.88 (1.1)	0.90 (1.5)	0.93 (1.3)	0.94 (1.0)
Acromioclavicular joint positions						
Internal/external rotation	0.98 (0.9)	0.98 (0.9)	0.98 (0.9)	0.90 (1.4)	0.95 (1.1)	0.89 (1.6)
Upward/downward rotation	0.93 (1.1)	0.97 (0.8)	0.93 (1.0)	0.80 (1.7)	0.91 (1.6)	0.92 (1.7)
Anterior/posterior tilt	0.95 (1.5)	0.98 (1.4)	0.97 (1.4)	0.96 (1.2)	0.95 (0.9)	0.93 (1.5)
Scapulothoracic joint positions						
Internal/external rotation	0.95 (1.9)	0.95 (1.6)	0.97 (1.6)	0.96 (1.9)	0.90 (2.1)	0.92 (2.2)
Upward/downward rotation	0.84 (2.2)	0.95 (1.6)	0.92 (1.9)	0.78 (2.1)	0.76 (2.1)	0.90 (1.7)
Anterior/posterior tilt	0.94 (1.4)	0.97 (1.0)	0.94 (1.2)	0.84 (5.1)	0.91 (1.3)	0.93 (1.7)

Abbreviation: SAB, scapular plane abduction.
**Values are intraclass correlation coefficient (standard error of measurement [deg]). Values represent the average reliability across all phases (raising/lowering) and angles (30°, 60°, 90°, 110°/120°) of humerothoracic elevation.*

JOINT-SPECIFIC PATTERNS OF MOTION

TABLES 2 through **4** present descriptive classifications of trends in sternoclavicular, acromioclavicular, and scapulothoracic joint position changes during humerothoracic elevation. This was accomplished by categorizing individual participants' pattern of motion from resting position with the arm at their side to 120° of humerothoracic elevation. The following operational definitions were used:

- Constantly: a near-linear change in position over time (eg, constantly retracting)
- Changing: inconsistency in the direction of position change over time (eg, retracting, then protracting)
- No change: less than a 1° change in joint position over the range of motion
- Delayed: little change in joint position during early angles of elevation followed by a near-linear change in position during the remaining range of motion

TABLE 2 Patterns of Sternoclavicular Joint Motion*

	Abduction		Flexion		Scapular Plane Abduction	
	Asymptomatic (n = 11)	**Symptomatic (n = 10)**	**Asymptomatic (n = 11)**	**Symptomatic (n = 10)**	**Asymptomatic (n = 11)**	**Symptomatic (n = 10)**
Protraction/retraction						
Constantly retracting	11 (100)	10 (100)	9 (82)	7 (70)	8 (82)	9 (90)
Changing	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (10)
No change	0 (0)	0 (0)	2 (18)	3 (30)	2 (18)	0 (0)
Elevation/depression						
Constant elevation	7 (64)	8 (80)	9 (82)	6 (60)	9 (82)	8 (80)
Constant depression	1 (9)	0 (0)	1 (9)	1 (10)	1 (9)	0 (0)
Changing	3 (27)	1 (10)	1 (9)	2 (20)	1 (9)	0 (0)
No change	0 (0)	1 (10)	0 (0)	1 (10)	0 (0)	2 (20)
Axial rotation						
Constant posterior rotation	9 (82)	2 (20)	10 (91)	7 (70)	9 (82)	8 (80)
Delayed posterior rotation	2 (18)	8 (80)	1 (9)	3 (30)	2 (18)	2 (20)

**Values are n (%) of participants demonstrating each pattern of motion.*

APPENDIX

TABLE 3

Patterns of Acromioclavicular Joint Motion*

	Abduction		Flexion		Scapular Plane Abduction	
	Asymptomatic (n = 11)	**Symptomatic (n = 10)**	**Asymptomatic (n = 11)**	**Symptomatic (n = 10)**	**Asymptomatic (n = 11)**	**Symptomatic (n = 10)**
Upward/downward rotation						
Constant upward rotation	7 (64)	8 (80)	7 (64)	8 (80)	9 (82)	10 (100)
Changing	2 (18)	2 (20)	4 (36)	2 (20)	2 (18)	0 (0)
No change	2 (18)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Internal/external rotation						
Constant internal rotation	9 (82)	9 (90)	10 (91)	9 (90)	10 (91)	8 (80)
Changing	1 (9)	1 (10)	0 (0)	0 (0)	0 (0)	0 (0)
No change	1 (9)	0 (0)	1 (9)	1 (10)	1 (9)	2 (20)
Anterior/posterior tilt						
Posterior tilt	9 (82)	9 (90)	11 (100)	10 (100)	11 (100)	10 (100)
No change	2 (18)	1 (10)	0 (0)	0 (0)	0 (0)	0 (0)

**Values are n (%) of participants demonstrating each pattern of motion.*

TABLE 4

Patterns of Scapulothoracic Joint Motion*

	Abduction		Flexion		Scapular Plane Abduction	
	Asymptomatic (n = 12)	**Symptomatic (n = 10)**	**Asymptomatic (n = 12)**	**Symptomatic (n = 10)**	**Asymptomatic (n = 12)**	**Symptomatic (n = 10)**
Upward/downward rotation						
Steady upward rotation	12 (100)	10 (100)	12 (100)	10 (100)	12 (100)	10 (100)
Internal/external rotation						
Constant internal rotation	4 (33)	2 (20)	5 (42)	5 (50)	7 (58)	5 (50)
Constant external rotation	3 (25)	4 (40)	2 (17)	3 (30)	3 (25)	2 (20)
Changing	0 (0)	0 (0)	1 (8)	1 (10)	0 (0)	1 (10)
No change	5 (42)	4 (40)	4 (33)	1 (10)	2 (17)	2 (20)
Anterior/posterior tilt						
Posterior tilt	12 (100)	8 (80)	12 (100)	10 (100)	12 (100)	10 (100)
No change	0 (0)	2 (20)	0 (0)	0 (0)	0 (0)	0 (0)

**Values are n (%) of participants demonstrating each pattern of motion.*

APPENDIX

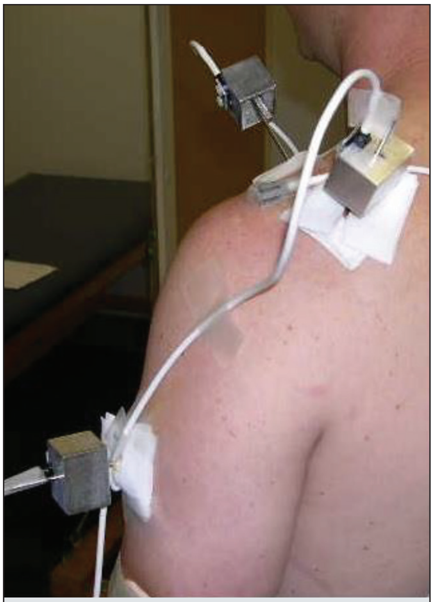

FIGURE 1. Experimental setup with bone pin insertion into clavicle, scapula, and humerus.

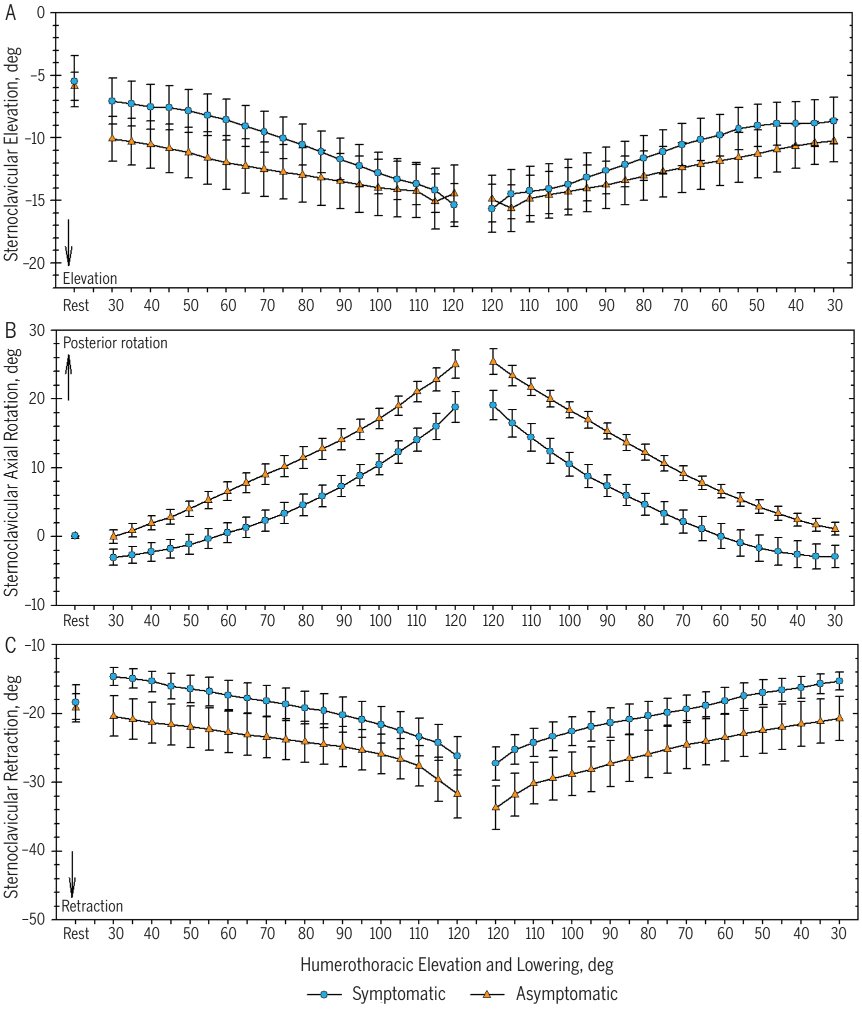

FIGURE 2. Sternoclavicular joint motion during shoulder flexion: (A) elevation/depression, (B) axial rotation, (C) protraction/retraction. The symptomatic group had less posterior rotation throughout the range of motion. Values are mean and unpooled standard error in degrees.

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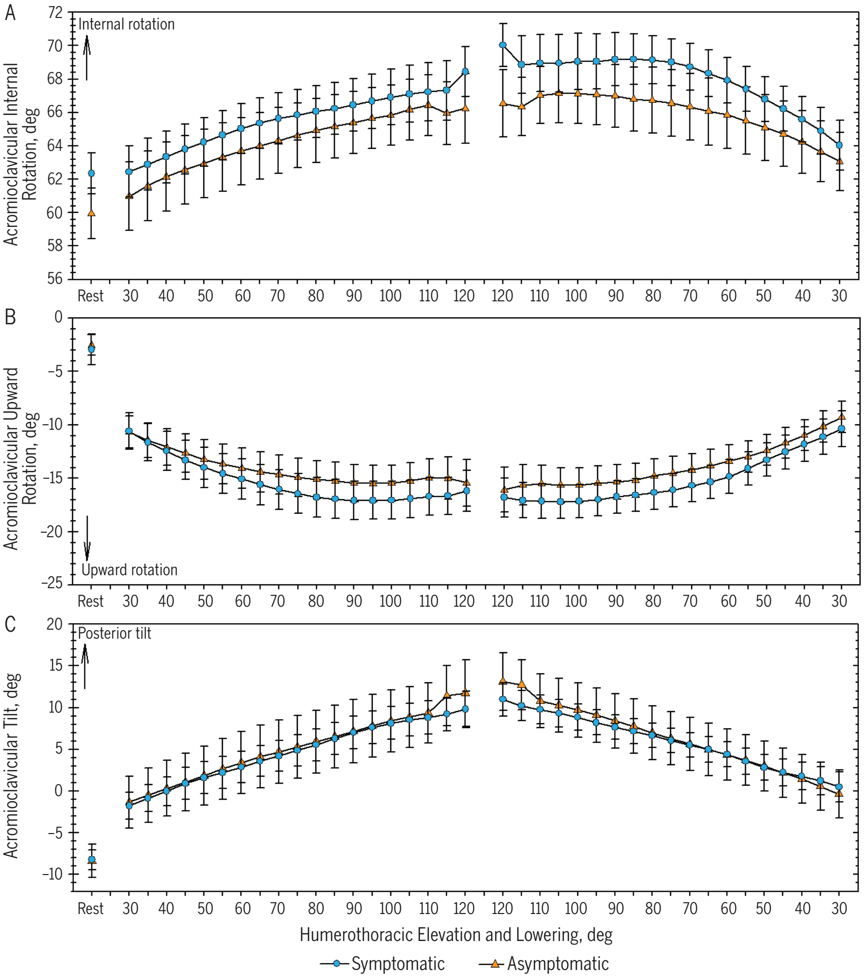

FIGURE 3. Acromioclavicular joint motion during shoulder flexion: (A) internal/external rotation, (B) upward/downward rotation, (C) anterior/posterior tilt. Values are mean and unpooled standard error in degrees.

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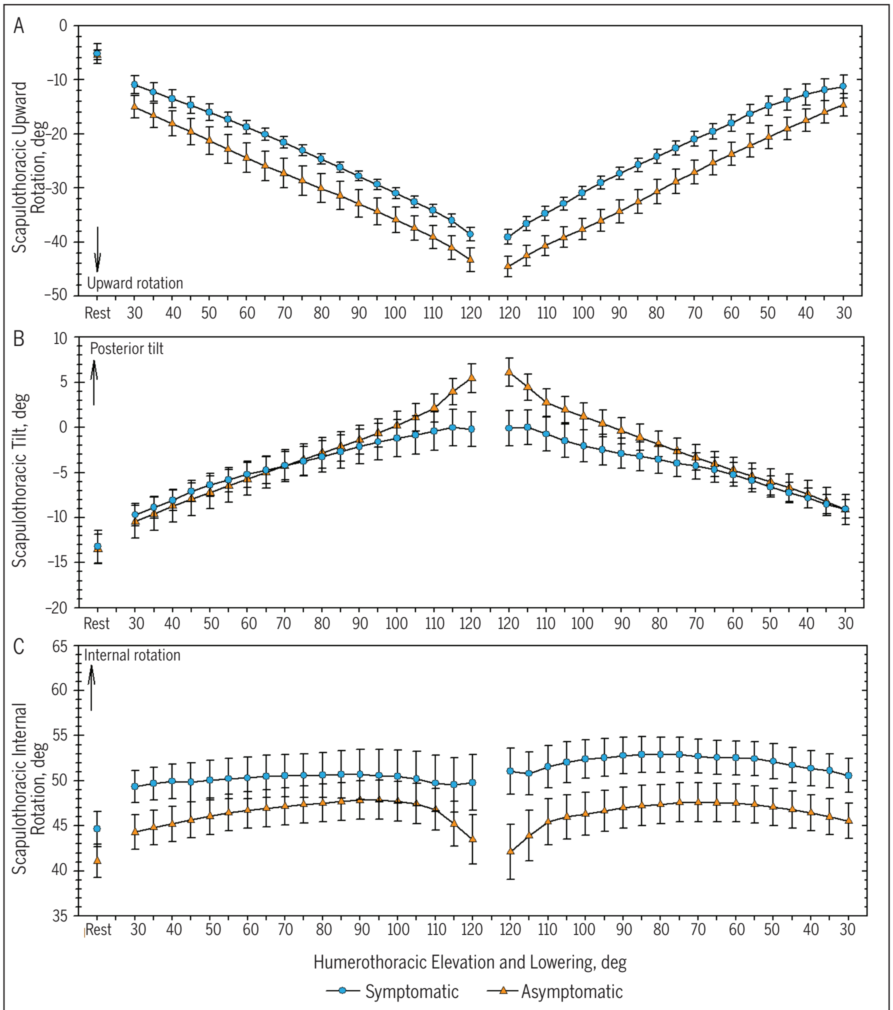

FIGURE 4. Scapulothoracic motion during shoulder flexion: (A) upward/downward rotation, (B) anterior/posterior tilt, (C) internal/external rotation. Values are mean and unpooled standard error in degrees.

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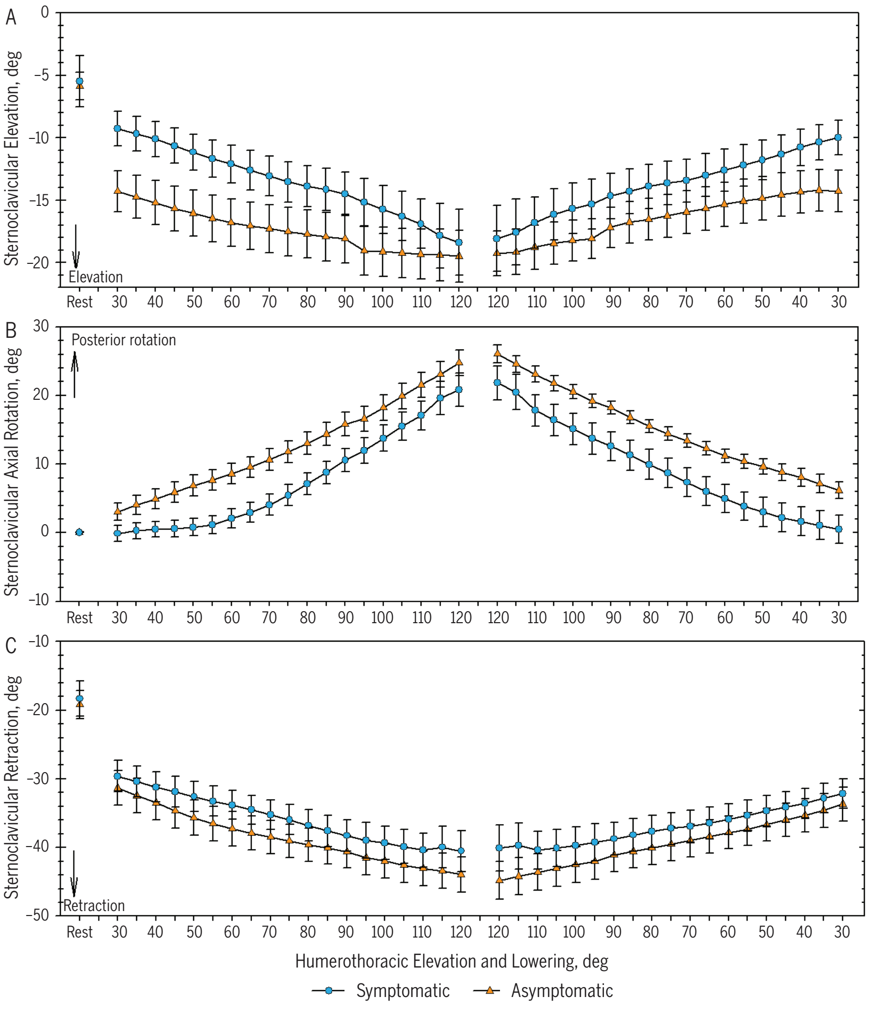

FIGURE 5. Sternoclavicular joint motion during shoulder abduction: (A) elevation/depression, (B) axial rotation, (C) protraction/retraction. The symptomatic group had less posterior rotation throughout the range of motion. Values are mean and unpooled standard error in degrees.

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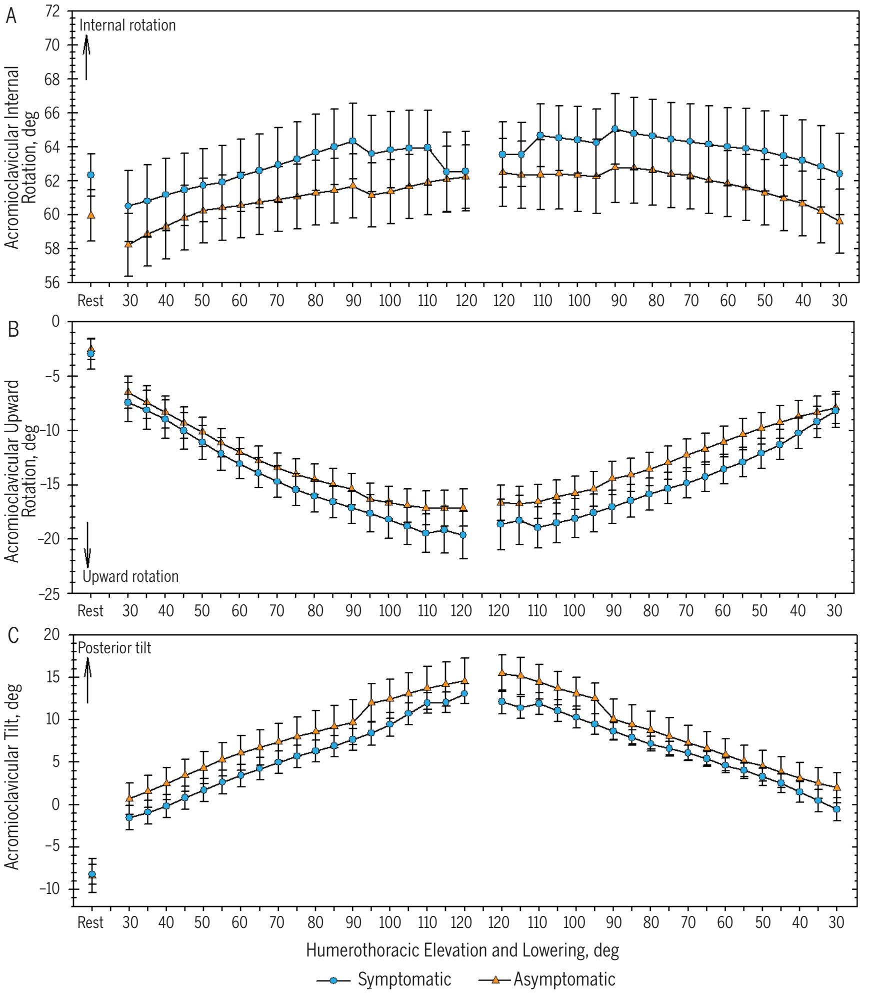

FIGURE 6. Acromioclavicular joint motion during shoulder abduction: (A) internal/external rotation, (B) upward/downward rotation, (C) anterior/posterior tilt. Values are mean and unpooled standard error in degrees.

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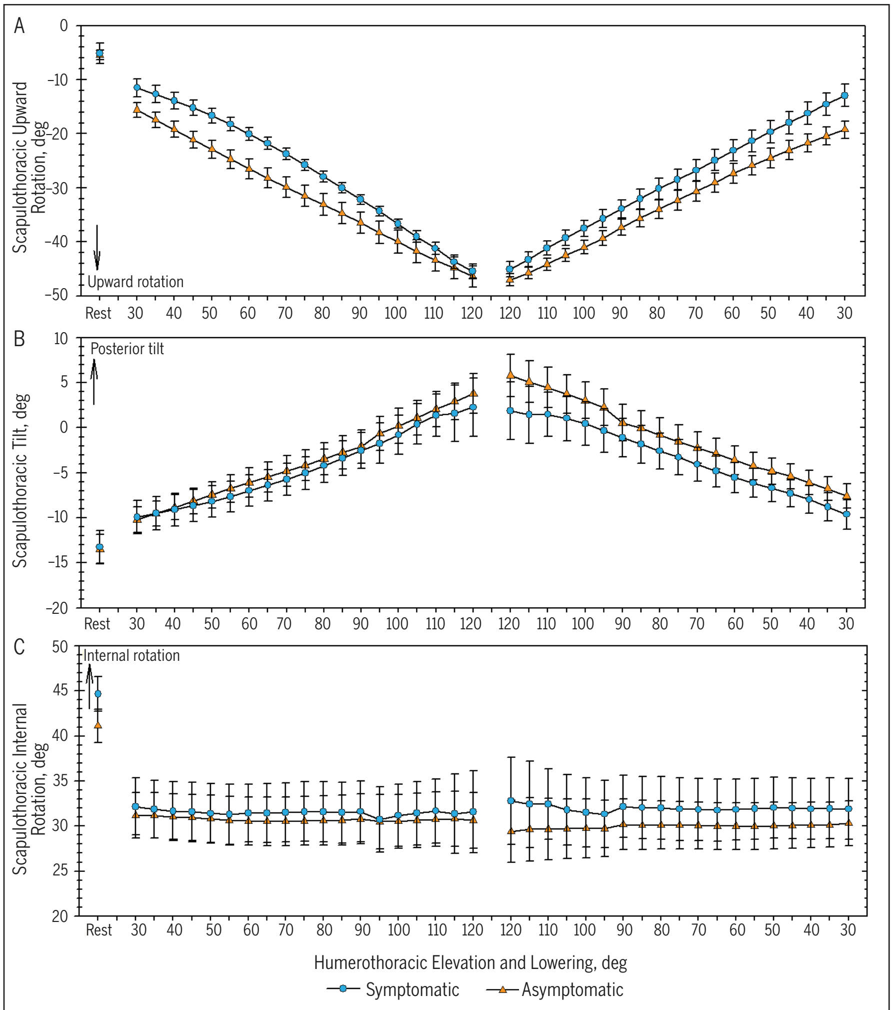

FIGURE 7. Scapulothoracic motion during shoulder abduction: (A) upward/downward rotation, (B) anterior/posterior tilt, (C) internal/external rotation. The symptomatic group had less upward rotation at 60° of arm raising and 30° of arm lowering. Values are mean and unpooled standard error in degrees.