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Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation

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Background: Scapular dyskinesis is an abnormal scapular motion or position during active arm elevation. Dyskinesis is theorized to contribute to impingement syndrome by decreasing the subacromial space. A corrective maneuver of the scapular assistance test (SAT) proposes to increase scapular upward rotation and posterior tilt to increase the subacromial space. The purpose of this study is to determine the influence that 1) scapular dyskinesis and 2) passive manual correction with the SAT have on subacromial space and 3-dimensional (3-D) scapular kinematics.
Materials and methods: Forty asymptomatic participants were classified with either obvious dyskinesis (n = 20) or normal motion (n = 20) using the scapular dyskinesis test. The anterior outlet of the subacromial space was measured via the acromiohumeral distance using ultrasound imaging and 3-D scapular orientation was assessed with electromagnetic motion analysis, with the arm at rest 45° and 90° of active elevation with and without the SAT, respectively.
Results: There were no differences in acromiohumeral distance or scapular kinematics with static active arm elevation between groups. The SAT increased scapular upward rotation, posterior tilt, and acromiohumeral distance in both groups. Participants with dyskinesis demonstrated greater scapular mobility in upward rotation with the SAT, but no additional increase in acromiohumeral distance.
Conclusion: Scapular dyskinesis identified during active motion did not result in different 3-D scapular orientation or acromiohumeral distance during active arm elevation in static positions; however, the SAT altered scapular kinematics and increased acromiohumeral distance. The SAT may be helpful to identify individuals where subacromial compression is producing symptoms, regardless of dyskinesis.
Level of evidence: Basic Science, Kinesiology and Anatomy Study in Asymptomatic Subjects.

Keywords: Scapular kinematics; AHD; scapular dyskinesis test; scapular assistance test; impingement; special tests; shoulder; subacromial space

Coordinated movement of the scapula is necessary for proper shoulder motion and function. During humeral elevation, the scapula rotates 3-dimensionally (3-D) into upward rotation, external rotation, and posterior tilt.[7,25,30] An abnormal position or movement of the scapula with

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active motion has been termed scapular dyskinesis,[19-21] and has been identified in individuals with subacromial impingement syndrome (SAIS)[11,15,16,22-24,26,29,31,45] and overhead athletes with and without shoulder pain.[38,39] Decreased scapular upward rotation, posterior tilt, and external rotation have been theorized to contribute to SAIS by decreasing the subacromial space.[12,24,42]

One study suggests scapular dyskinesis reduces subacromial space. Silva et al found asymptomatic, elite, junior tennis players with dyskinesis had a greater reduction in subacromial space, measured by the acromiohumeral distance (AHD) from ultrasound images, from 0° to 60° abduction compared to athletes without dyskinesis.[38] However, the subacromial space was imaged while the arm was passively positioned, and criteria used to identify dyskinesis were not previously established. To date, the influence that scapular dyskinesis may have on the subacromial space during active humeral elevation is unknown.

One clinical method to assess scapular motion, the scapular dyskinesis test, is a reliable and validated observational method to identify scapular dyskinesis.[27,39] Quantified with motion analysis, athletes with obvious dyskinesis using this clinical test have decreased scapular upward rotation, as compared to individuals without dyskinesis.[39] The scapular assistance test (SAT) is a symptom reproduction test used to identify aberrant scapular motion which may contribute to the presence of shoulder pain.[34] With the SAT, an examiner passively assists the scapula into upward rotation and posterior tilt during humeral elevation.[19,20,34] In patients with impingement, the SAT is considered a corrective passive maneuver to decrease pain,[21] presumably due to an increase subacromial space. It is unknown whether individuals with scapular dyskinesis would differ from individuals without dyskinesis in changes in scapular orientation or AHD with manual assistance using the SAT.

The purposes of this study were to: 1) determine the influence that scapular dyskinesis has on scapular kinematics and AHD; 2) compare the influence that passive manual correction with the scapular assistance test (SAT) has on AHD and 3-D scapular kinematics between individuals with dyskinesis and individuals without. Hypothetically, 3-D scapular kinematics and AHD would differ in asymptomatic participants with obvious scapular dyskinesis compared to participants without. Additionally, participants with scapular dyskinesis would demonstrate greater change in 3-D scapular position and AHD with the SAT than participants without dyskinesis.

Figure 1 Participant classified with obvious scapular dyskinesis during the weighted abduction task of the scapular dyskinesis test.

Materials and methods

Participants

Forty healthy participants (20 with dyskinesis; 20 with normal motion), between ages of 18 and 70 years, free from shoulder or upper arm pain for at least 6 months participated in this study. Individuals with symptoms produced by cervical spine motion, systemic connective tissue disease, a history of shoulder fracture, surgery, or known shoulder pathology were excluded.

Approximately 210 potential participants from an urban university community were screened for potential eligibility by a single examiner, of whom 42 were scheduled for testing. Willing participants in the scapular dyskinesis cohort were included if they presented with obvious scapular dyskinesis, as defined by 2 independent examiners, a physical therapist with 15 years of orthopedic clinical experience, and a certified athletic trainer with 3 years of experience using the scapular dyskinesis test. Participants with normal scapular motion (normal group) by the same 2 examiners were included and matched to participants with dyskinesis on the basis of age (+/− 5 years), gender, and arm dominance of shoulder tested (dominant; nondominant). Both examiners underwent standardized online training designed by the developers of the test.[27] Only participants classified independently by both examiners (100% agreement) with either obvious dyskinesis (dyskinesis group) or normal scapular motion (matched normal group) using the operational definitions of the scapular dyskinesis test[27] were enrolled. The scapular dyskinesis test consists of 5 repetitions of bilateral, active, shoulder flexion, and abduction holding either 1.4 kg (3 lb) or 2.3 kg (5 lb) weights based on body mass.[27] Figure 1 illustrates a participant with obvious dyskinesis. Prior to initiating the study, a sample size of 20 participants per group was determined to provide greater than 80% power to detect a meaningful difference in AHD, defined as the upper boundary of the 90% confidence interval for the minimal detectable change (2.0 mm), with a common standard deviation of 2.0 mm in a pilot study.[35,36]

Instrumentation

The Polhemus 3Space Fastrak electromagnetic-based motion capture system (Polhemus, Colchester, VT, USA), with a sampling rate of 30 Hz, per sensor was used with Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL, USA) to collect 3-D kinematic data of the scapula, humerus, and trunk. The electromagnetic tracking unit consists of a transmitter, 4 receivers, and a computer. The transmitter emits a magnetic field (measurement range of 0.45-2.4 m) detected by receivers affixed to the thorax, scapula, and humerus. The manufacturer reported accuracy of the electromagnetic tracking device is 0.8 mm and 0.15°.[1] This surface-based electromagnetic motion capture method to track scapular motion has been validated using bone pins.[17] Average errors for skin mounted receivers is 1.06 mm linear displacement and 3.56° rotation for scapular motions during humeral elevation, with the greatest error occurring above 120° of humeral elevation.[17]

A diagnostic US unit, LogiQ*e* (GE Healthcare, Wisconsin, USA) with a 4-12 MHz adjustable linear array transducer set at a frequency of 8.0 MHz, was used to capture images in B-mode for subacromial space measurement. The subacromial space was defined as the AHD, the shortest linear distance between the humeral head and the anterior inferior tip of the acromion, using onscreen calipers. This measurement represents a linear measure of the anterior outlet of the subacromial space. US-generated AHD measures have demonstrated satisfactory reliability with intraclass correlation coefficients from .86-.91 with the arm at rest, 45°, 60°,[8] and 90°[44] and concurrent validity with radiographs (R = .77-.85).[2,3]

3-D scapular kinematic data collection

Three electromagnetic receivers were attached to study participants using double-sided tape (3M Health Care, St Paul, MN, USA) and further secured with CoverRoll (Beiersdorf, Norwalk, CT, USA). Receivers were placed on the thorax over the spinous process of T3, the posterior-lateral acromion, and the posterior aspect of the distal humerus, further secured with a Velcro cuff. The fourth receiver, a stylus, was used to digitize anatomical landmarks on the subject's thorax, scapula, and humerus, identified by palpation, following recommendations from the International Society of Biomechanics (ISB).[46] Digitization allowed transformation of the sensor position and orientation into anatomically-based position and orientation data of the humerus and scapula, with respect to the thorax. Euler angle sequences for humeral (Y-X'-Y'') and scapular (Y-X'-Z'') rotations were based on ISB recommendations.[46] Scapular rotations (external rotation, upward rotation, and posterior tilt) occur around orthogonal axes as previously illustrated and defined.[28,29] Scapular movements into the directions of upward rotation, posterior tilt, and external rotation were defined as positive values to ease clinical interpretation.

US imaging

The position of the US probe was standardized so that the anatomical landmarks of the humeral head and acromion were consistently identified. With participants in a seated position, the US probe was placed parallel to the flat surface at the most anterior aspect of the acromion, identified by palpation, with the long axis of the probe in the plane of the scapula. Images were saved on the US unit for later AHD measurements made by a single examiner blinded to SAT condition and arm angle. Examiners were not blinded to group allocation.

Testing procedure

Shoulder kinematic data and US images were collected sequentially, in random order determined by drawing. Participants were seated in an armless chair with the lumbar spine firmly approximating the seat back. With the thumb facing forward, the arm was positioned at rest, 45°, or 90° of active shoulder scapular plane elevation verified with an inclinometer placed parallel to the long axis of the humerus. The scapular plane was defined as 30° anterior to the frontal plane verified with a goniometer. A second examiner performed the SAT, while the first examiner captured an US image or manually triggered the SAT event during continuous scapular kinematic data collection. The same examiner performed the US imaging and manual trigger of SAT to improve the consistency of these measures. The SAT was performed as previously described, with the examiner facilitating upward rotation and posterior tilting of the scapula by pushing upward and laterally on the inferior angle of the scapula, and by pulling the superior aspect of the scapula posteriorly.[34] While the SAT is typically performed as the patient elevates the arm through a full arc of motion,[34] in this study, the SAT maneuver was applied to the scapula while the participant actively maintained a static arm position, due to difficulty obtaining reliable measures of AHD during humeral elevation through a full arc of motion in pilot testing. Participants rested the upper extremity in a suspension harness between trials. Two consecutive trials were performed at each arm angle (rest, 45°, and 90°), under each condition (with and without SAT), in random order by drawing.

Data analysis

Test-retest intrarater reliability were calculated for dependent variables using intraclass correlation coefficient ($ICC_{3,2}$) analyses.[37] Descriptive statistics, including standard error of the measure (SEM), were computed for all variables using the formula: SEM = standard deviation X square root of (1 − ICC). Independent t tests were used to compare group characteristics. Normality was confirmed by testing skewness and kurtosis on each dependent variable for each angle under each condition. Normality was accepted for all dependent variables, such that parametric statistics were appropriate for further analysis. To examine the effect of dyskinesis, we compared 3-D scapular kinematics and AHD between groups using separate mixed-model analysis of variance (ANOVA) with factors of group (dyskinesis; normal), arm angle (rest, 45° and 90°), and interactions. To determine the effects of passive manual correction using the SAT on AHD and 3-D scapular position, separate $2 \times 2 \times 3$ mixed-model ANOVAs were used with effects of SAT (with SAT; without SAT), group, arm angle, and interactions. Statistical significance was set at $\alpha = .05$. Post hoc testing was performed with linear contrasts, with a priori comparisons of interest to include the main effects or interactions of group and SAT condition, using a Bonferroni adjusted alpha to account for multiple comparisons. All analyses were performed using SAS Software (JMP 8.1; SAS Institute Inc, Cary, NC, USA).

Results

There were 11 females and 9 males in each group, with a mean age (SD) of 26.6 (6.0) years. Obvious dyskinesis was present in the dominant shoulder in 55% (n = 11/20).

There were no significant differences in participant characteristics ($P > .05$) with regard to age, height, or body mass between groups. Intrasession test-retest reliability of the AHD ($ICC_{3,2}$ = 0.88-0.96) and scapular kinematics ($ICC_{3,2}$=0.98-0.99) performed during 2 separate trials were excellent. The SEM of the AHD ranged from 0.5-1.1 mm across the 3 arm positions. The SEM for scapular upward rotation, posterior tilt, and external rotation was 0.8-2.5°, respectively, across all arm positions. The reliability of scapular orientation induced by the SAT was excellent ($ICC_{3,2}$ = 0.97-0.99).

Effects of scapular dyskinesis

Scapular kinematics and AHD in participants in each group are shown in Figure 2. Examining the effects of dyskinesis on 3-D scapular kinematics, there were no statistically significant interactions with upward rotation ($P = .934$), posterior tilt ($P = .524$), external rotation ($P = .768$), or main effects of dyskinesis in either upward rotation ($P = .729$), posterior tilt ($P = .669$), or external rotation ($P = .943$). Examining the influence of dyskinesis on AHD, there was no significant interaction ($P = .491$) or main effect ($P = .754$) of dyskinesis on AHD. Thus participants with dyskinesis did not differ from participants classified as normal in 3-D scapular kinematics or AHD with the arm at rest, 45°, or 90° of static active arm elevation. Mean scapular kinematics and AHD for all participants are found in Table I.

Effects of scapular assistance test

Results of the 2 × 2 × 3 mixed-model ANOVAs to compare the influence of the SAT between participants with dyskinesis and without are shown in Table II and Figures 3 and 4. With regard to the influence of the SAT on scapular upward rotation, the 3-way interaction (group × arm angle × SAT condition) was not significant. Thus the influence of dyskinesis on upward rotation did not depend on arm angle or SAT condition. There was no significant 2-way interaction of group by arm angle; however, there was a significant 2-way interaction of group by SAT condition. Thus the presence of dyskinesis influenced the effect of SAT on scapular upward rotation, regardless of arm angle. As shown in Figure 3, participants with scapular dyskinesis demonstrated a significantly greater increase in scapular upward rotation with the SAT (10.0°; SE = 1.1) by 3.1° (SE of difference = 1.5), compared to participants without dyskinesis (6.9°; SE = 1.1). There also was a significant 2-way interaction of SAT condition by arm angle. Within both groups, the SAT induced greater scapular upward rotation with the arm at the rest (13.2°; SE = 1.3), compared to 45° (7.3°; SE = 1.3) and 90° (4.9°; SE = 1.3) positions. For scapular posterior tilt, there was a significant main effect of SAT condition. Therefore, regardless of arm angle, the SAT increased scapular posterior tilt by 4.8° (SE = 1.0), but did not differ between dyskinesis and normal groups. For passive external rotation, there was a significant 2-way interaction of SAT condition by arm angle. The SAT decreased scapular external rotation at rest (mean 6.5°, SE = 0.7), 45° (mean 4.5°; SE = 0.7), and 90° (mean 3.8°; SE = 0.7) of scapular plane elevation.

Results for the influence of the SAT on AHD in participants with and without dyskinesis are shown in Table II and Figure 4. There were no significant 3- or 2-way interactions of arm angle by SAT, group by SAT, or group by arm angle. Thus the presence of dyskinesis did not influence AHD, regardless of SAT condition or arm angle. There was a significant main effect of SAT condition. The SAT increased AHD ($P < .001$) by 1.4 mm (SE = 0.2) averaged across all arm angles and in both groups. With all participants, the mean increase in AHD was 1.8 mm (SE = 0.36) ($P < .001$) and 1.6 mm (SE = 0.36) ($P < .001$) with the SAT at 45° and 90°, respectively, as compared without the SAT.

Discussion

Aberrant motion identified as scapular dyskinesis has been proposed to influence subacromial space. Despite the presence of observable obvious scapular dyskinesis in participants in this study, the 3-D orientation of the scapula was not altered in static positions of arm elevation compared to participants without dyskinesis. This was contrary to our hypothesis and findings of prior studies. Tate et al[39] found decreased scapular upward rotation (8°) with 3-D motion analysis in athletes classified with obvious dyskinesis using the scapular dyskinesis test, compared to athletes with normal scapular motion.

In the current study, 3-D scapular kinematics was evaluated with the arm held statically in discrete positions of scapular plane elevation, without a weight. Less superior migration of the humerus on the glenoid has been found when the arm is actively held in discrete static positions, as compared to dynamically through a full arc.[41] Scapular kinematic alterations are more evident during dynamic testing conditions than during static conditions,[45] and with resistance (holding a weight) compared to no resistance[40] in individuals with shoulder pain. Thus, examination of scapular position in static arm positions may not have been challenging enough to reveal potential movement deficits that were observed visually during the screening examination. Furthermore, measurements of scapular kinematics during static arm positions likely do not adequately capture the dynamic scapular alterations present with obvious scapular dyskinesis. This finding highlights the importance of including a dynamic evaluation of scapular motion in clinical examination of individuals with or without shoulder pain.

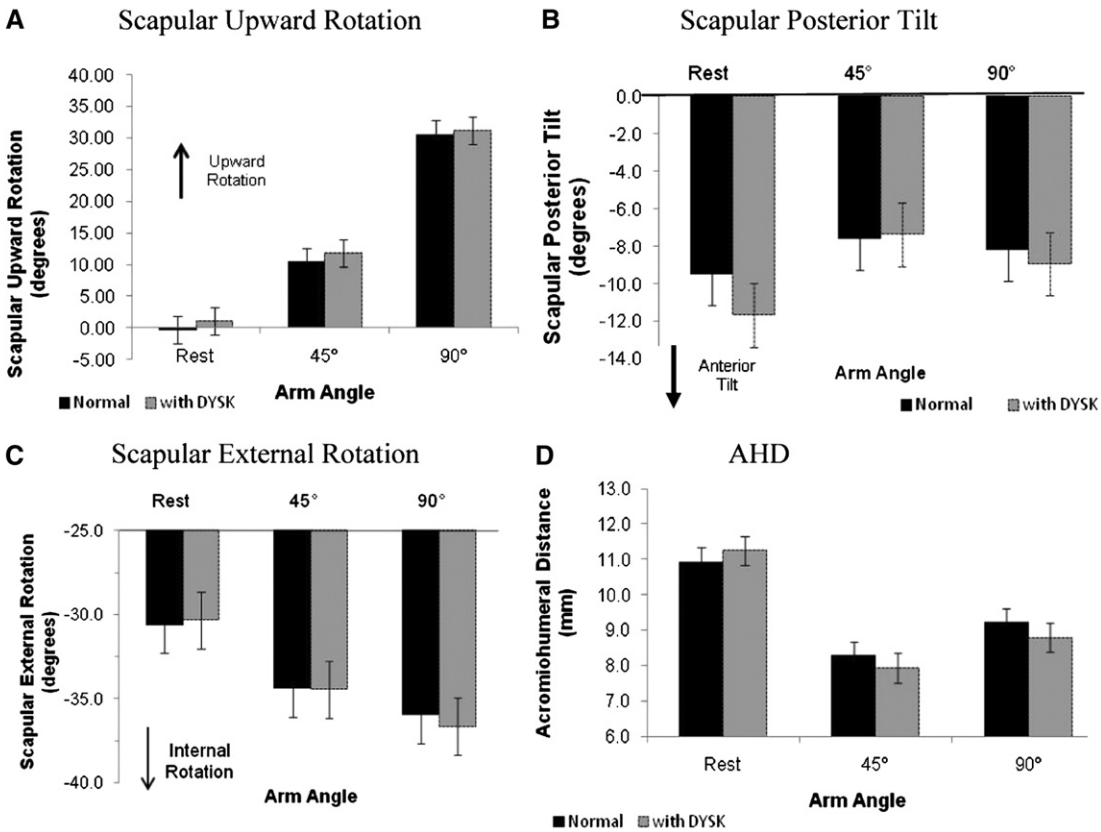

Figure 2 Mean scapular kinematics and acromiohumeral distance (AHD) without SAT in individuals with scapular dyskinesis (DYSK) and without (Normal). *Error bars* represent standard error of the mean. Scapular **(A)** upward rotation (positive values= upward rotation), **(B)** posterior tilt (positive values= posterior tilt), **(C)** external rotation (positive values = external rotation), and **(D)** AHD. Values for scapular posterior tilt and external rotation are negative and remain negative, because the scapula is anteriorly tilted and internally rotated at each arm position.

The AHD did not differ between the cohort with obvious scapular dyskinesis and those without dyskinesis at any of the 3 arm positions measured. These results did not confirm our hypothesis, and differ somewhat from a prior study. Silva et al found a greater reduction in AHD from rest to 60° elevation in elite tennis players with dyskinesis, compared to players without.[38] Our methods of AHD measurement differ in 2 major ways from those of Silva et al. Silva et al captured images of the AHD at varying aspects along the lateral acromion deemed as the narrowest point, not at the anterior aspect where subacromial impingement occurs.[6,12] Moreover, in the prior study, the subacromial space was imaged while the arm was passively positioned, not during active elevation. Furthermore, different constructs of scapular dyskinesis may have been used, as methods of classification of dyskinesis were not the same between studies.

Participants in the current study were not engaged in elite or collegiate level athletics and were asymptomatic. In the study by Tate et al,[39] participants were collegiate overhead athletes, many of whom had shoulder pain. In the study by Silva et al, participants were also overhead athletes, elite junior tennis players. Thus, factors unique to competitive overhead athletes with clinically observed scapular dyskinesis may contribute to altered kinematics or diminished AHD such as humeral retroversion or posterior shoulder tightness. Scapular dyskinesis is likely multifactorial. Abnormal scapular motion has been associated with: decreased pectoralis muscle length,[5] rotator cuff, or shoulder muscle fatigue[9,10,43]; thoracic position[18]; muscle activity[13]; and a loss of glenohumeral joint internal rotation range of motion.[4] Not only can these factors potentially alter scapular kinematics differently, many may not affect scapular kinematics at the discrete static angles or with static testing used in this study.

Despite the lack of differences in 3-D kinematics or AHD between groups, results of the current study support the notion by Kibler et al,[19,20] that passive manual correction of the scapula with the SAT increases scapular upward rotation and posterior tilt, which influences the subacromial space. Thus the SAT may relieve compression on the tendon or bursa, and help identify individuals with pain related to subacromial impingement. Interestingly, the SAT also increased scapular internal rotation across all arm angles. This may have occurred due to performing the SAT while the participants actively held the arm in static

Table I 3-D scapular kinematics and acromiohumeral distance without SAT in all participants (n = 40)

Arm Angle	Scapular Posterior Tilt (degrees)								
	Normal			With DYSK			Difference		
	Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Rest	−9.5	1.7	−12.9, −6.0	−11.7	1.7	−15.1, −8.2	2.2	2.5	−5.0, 9.4
45°	−7.6	1.7	−11.0, −4.1	−7.4	1.8	−10.9, −3.8	−0.2	2.5	−7.5, 7.1
90°	−8.2	1.7	−11.6, −4.7	−8.9	1.7	−12.4, −5.5	0.8	2.5	−6.5, 8.0
Arm Angle	**External Rotation (degrees)**								
	Normal			With DYSK			Difference		
	Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Rest	−30.6	1.7	−34.0, −27.2	−30.3	1.7	−33.8, −26.9	0.3	2.4	−6.9, 7.4
45°	−34.4	1.7	−37.8, −31.0	−34.4	1.7	−37.9, −31.0	0.0	2.4	−7.2, 7.2
90°	−36.0	1.7	−39.4, −32.5	−36.7	1.7	−40.1, −33.2	−0.7	2.4	−7.8, 6.5
Arm Angle	**Acromiohumeral Distance (mm)**								
	Normal			With DYSK			Difference		
	Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Rest	10.9	0.4	10.1, 11.8	11.3	0.4	10.4, 12.1	−0.4	0.6	−1.5, 0.8
45°	8.3	0.4	7.4, 9.1	7.9	0.4	7.1, 8.8	0.4	0.6	−1.5, 0.8
90°	9.2	0.4	8.4, 10.1	8.8	0.4	7.9, 9.6	0.4	0.6	−0.7, 1.6

DYSK, obvious scapular dyskinesis; *SE,* standard error; *95% CI*, 95 percent confidence interval.

Table II Summary of scapular kinematic and acromiohumeral distance results using 3-factor mixed model ANOVAs for the influence of passive manual assistance, with the scapular assistance test in participants classified with obvious dyskinesis (DYSK) and normal

Source	Scapular Kinematics						
	df	UR		PT		ER	
		F Ratio	*p*-value	F Ratio	*p*-value	F Ratio	*p*-value
Group	1, 38	0.7	0.422	0.2	0.667	0	0.998
Arm Angle	2, 190	432.0	<0.001*	15.2	<.001	40.9	<0.001*
Group x Arm Angle	2, 190	0.4	0.657	0.8	0.432	0.1	0.900
SAT condition	1, 190	126.7	<0.001*	74.1	<.001	143.0	<0.001*
Group x SAT condition	1, 190	4.4	0.038	0.0	0.908	0.1	0.705
Arm Angle x SAT condition	2, 190	10.8	<0.001*	0.8	0.462	3.7	0.026*
Group x Arm Angle x SAT condition	2, 190	0.1	0.889	0.1	0.912	0.1	0.880
	Acromiohumeral Distance						
Group	1, 38	0.5	0.466				
Arm Angle	2, 189	46.1	<0.001*				
Group x Arm Angle	2, 189	1.5	0.222				
SAT condition	1, 189	42.5	<0.001*				
Group x SAT condition	1, 189	0.7	0.390				
Arm Angle x SAT condition	2, 189	2.8	0.066				
Group x Arm Angle x SAT condition	2, 189	0.0	0.958				

UR, upward rotation; *PT*, posterior tilt; *ER*, external rotation.
* statistically significant.

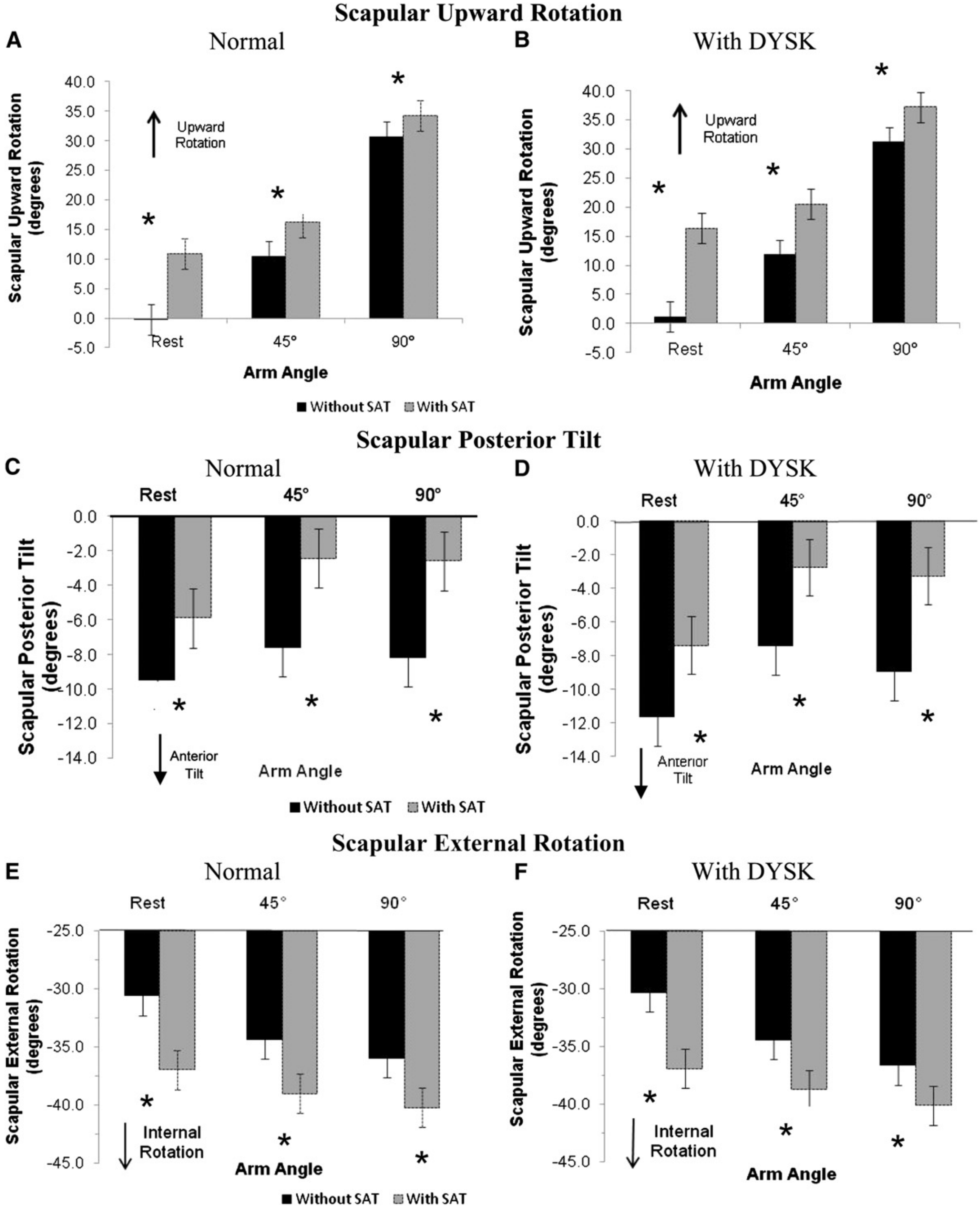

Figure 3 Mean scapular kinematics with and without passive alteration with the scapular assistance test (SAT) in individuals with scapular dyskinesis (DYSK) and without (Normal). *Error bars* represent standard error of the mean. Scapular upward rotation (positive values = upward rotation) in **(A)** normal and **(B)** DYSK, posterior tilt (positive values = posterior tilt) in **(C)** normal and **(D)** DYSK, and external rotation (positive values= external rotation) in **(E)** normal and **(F)** DYSK. Values for posterior tilt and external rotation are negative and remain negative, because the scapula is anteriorly tilted and internally rotated at each arm position. Asterisk (*) indicates significant difference between with and without SAT.

elevated positions, as opposed to participants performing elevation through a full arc of motion. Although internal rotation is theorized to reduce the subacromial space, the AHD in this study increased. However, the largest changes in scapular internal rotation were at rest while the largest changes in AHD were at 45° and 90°. Thus, scapular

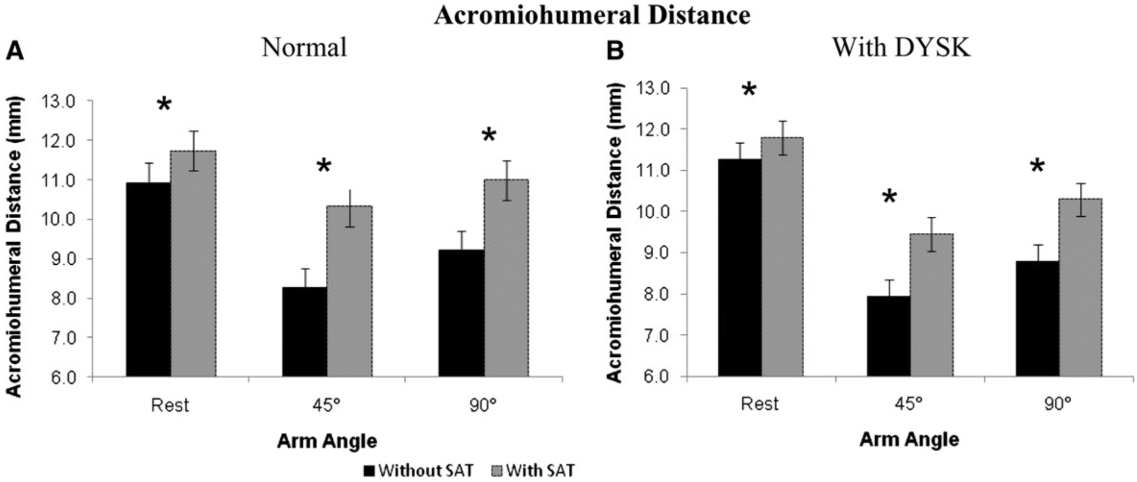

Figure 4 Acromiohumeral distance with and without passive alteration with the scapular assistance test (SAT). *Error bars* represent the standard error of the mean. Participants with **(A)** normal scapular motion with the scapular dyskinesis test, and **(B)** obvious scapular dyskinesis with the scapular dyskinesis test. Asterisk (*) indicates significant difference between with and without SAT.

internal rotation may have little influence on the subacromial space particularly in the presence of increased scapular upward rotation and posterior tilt.

While greater scapular upward rotation was induced with the SAT in participants with dyskinesis, compared to those without, the clinical meaning of this finding is unclear. Increased passive scapular upward rotation with the SAT in individuals with dyskinesis may be indicative of scapulothoracic joint hypermobility, which may increase the demand for dynamic control of the scapular stabilizers, including the serratus anterior and middle and lower trapezius muscles, thereby contributing to the presence of dyskinesis during loaded, dynamic arm elevation conditions. Increased scapular upward rotation with passive manual assistance of the SAT may be associated with increased soft tissue length or thoracic spine mobility in individuals with dyskinesis. Further study is warranted to determine whether pain and pain response to the SAT may influence changes in AHD.

Limitations

The AHD and 3-D scapular orientation may differ in other planes of arm elevation, at other arm angles, or when tested dynamically through a full range of shoulder motion. We selected these discrete arm positions because SAIS is characterized by pain during elevation,[32,33] typically in an arc of motion where the greater tuberosity passes beneath and approximates the acromion.[14] Several studies have shown that with humeral elevation greater than 90°, the rotator cuff tendons pass medially beyond the acromion so that they are no longer susceptible to impingement within the subacromial space.[6,12,14] Measures of AHD captured with ultrasound are linear measures that do not take into account what may occur at other aspects or volume of the subacromial space. Additionally, motion analysis using surface receivers are susceptible to skin artifact. To account for this, we did not examine 3-D kinematics above 90° of elevation, which eliminated the range of motion, where skin artifact is the greatest. In pilot study, error due to skin artifact with the SAT was less than 2° in scapular upward rotation, posterior tilt, and external rotation,[35] which are considerably less than changes we found with SAT, and therefore likely to represent true change. This study examined asymptomatic individuals with scapular dyskinesis; thus the results may not be applied to individuals with shoulder pain. Lastly, the SAT has been previously described as performed during active elevation through a full range of elevation. In this study, we performed the SAT during static arm elevation, which may yield different results in AHD and 3-D scapular kinematics. This warrants further study. Despite these limitations, the results of this study provide valuable information regarding scapular dyskinesis.

Conclusions

Scapular dyskinesis is an abnormal scapular position during arm elevation. However, scapular dyskinesis identified during a clinical exam with weighted arm elevation has little effect on 3-D scapular orientation and AHD, with the arm held in static positions in asymptomatic individuals. Therefore, examination of scapular motion during active elevation through a full arc of motion, and perhaps with resistance, may improve detection of motion abnormalities compared to static tests. The SAT, a clinical examination method performed by manually assisting the scapula into upward rotation and posterior tilt in theory, would increase the subacromial space, or AHD. The SAT does appear to increase AHD, concurrent with increased scapular posterior tilt and upward rotation, and therefore may be helpful identifying individuals where subacromial compression is producing symptoms. In participants with dyskinesis, there was greater scapular upward rotation with the SAT than participants without, indicating potential scapular hypermobility. Research is needed to determine whether scapular dyskinesis associated with pain differs in regard to 3-D kinematics and AHD during dynamic and static active arm elevation.

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