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Scapular asymmetry in participants with and without shoulder impingement syndrome; a three-dimensional motion analysis

Elif Turgut PT, PhD [a,*], Irem Duzgun PT, PhD [a], Gul Baltaci PT, PhD, FACSM [b]

[a] Hacettepe University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, 06100, Samanpazari, Ankara, Turkey
[b] Private Guven Hospital, Şimşek Sk. 29 D, Kavaklıdere, 06540 Ankara, Turkey

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ABSTRACT

Background: This study analyzed the dynamic three-dimensional scapular kinematics and scapular asymmetry in participants with and without shoulder impingement syndrome.
Methods: Twenty-nine participants with shoulder impingement syndrome, have been suffering from unilateral shoulder pain at the dominant arm lasting more than six weeks and thirty-seven healthy controls participated in the study. Scapular kinematics was measured with an electromagnetic tracking device during shoulder elevation in the sagittal plane. Data for bilateral scapular orientation were analyzed at 30°, 60°, 90°, and 120° of humerothoracic elevation and lowering. The symmetry angle was calculated to quantify scapular asymmetry throughout shoulder elevation.
Findings: Statistical comparisons indicated that the scapula was more downwardly rotated ($p < 0.001$) and anteriorly tilted ($p = 0.005$) in participants with shoulder impingement syndrome compared to healthy controls. Side-to-side comparisons revealed that the scapula was more anteriorly tilted on the involved side of participants with shoulder impingement syndrome ($p = 0.01$), and the scapula was rotated more internally ($p = 0.02$) and downwardly ($p = 0.01$) on the dominant side of healthy controls. Although there were side-to-side differences in both groups, symmetry angle calculation revealed that the scapular movement was more asymmetrical for scapular internal and upward rotation in individuals with shoulder impingement syndrome when compared with healthy controls ($p < 0.05$).
Interpretation: The findings of the study increase our knowledge and understanding of scapular alterations in symptomatic and asymptomatic populations, which creates biomechanical considerations for shoulder assessment and rehabilitation.

1. Introduction

Shoulder elevation is a complex motion that occurs as a result of combined movement of the humerus, clavicle, and scapula (Inman et al., 1996). Scapular mobility and stability plays a critical role for supporting a wide range of glenohumeral motion and normal shoulder function (Kibler, 1998). The literature shows that alterations in scapular kinematics are often related to various shoulder disorders such as shoulder impingement syndrome (SIS) (Ludewig and Reynolds, 2009). However, there has been no consensus for both describing normal scapular kinematics that should be observed in the asymptomatic population, and describing kinematic alterations in participants with SIS (Struyf et al., 2011; Timmons et al., 2012). The majority of research has reported that participants who were diagnosed with SIS have decreased scapular upward rotation, external rotation, and posterior tilt during shoulder elevation in different movement planes (Endo et al., 2004; Hebert et al., 2002; Ludewig and Cook, 2000; Lukasiewicz et al., 1999). These altered scapular kinematic differences observed in patients with SIS have been theoretically related to a decrease in subacromial space and compression of rotator cuff tendons (Timmons et al., 2012).

Quantifying differences in kinematics between limbs has been accepted as a common clinical and research objective. Kinematic symmetry has been studied to describe normal levels of asymmetry in healthy individuals, especially for lower extremity kinematics obtained during gait analysis (Gundersen et al., 1989; Herzog et al., 1989), to associate the asymmetry with pathology and to investigate the effect of a specific intervention (Robinson et al., 1987). With regards to the upper extremities, besides kinematic alterations across symptomatic and asymptomatic populations or overhead athletes, researchers have also placed some emphasis on scapular asymmetry. Kibler (Kibler, 1998) defined scapular asymmetry based on static, two-dimensional clinical examination of the scapular upward rotation and suggested that symmetry in scapular motion should be considered as criteria for normal scapular motion. In a Moiré topographic study, Warner et al. (Warner et al.,

* Corresponding author.
E-mail addresses: elifcamci@hacettepe.edu.tr (E. Turgut), iremduzgun@hacettepe.edu.tr (I. Duzgun), ybaltaci@hacettepe.edu.tr (G. Baltaci).

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1992) reported that scapular asymmetry was observed in 57% of participants with SIS and in 14% of healthy controls. Moreover, studies using motion analysis systems, which allow for the assessment of complex scapular position and orientation during dynamic upper extremity functions (Karduna et al., 2001), showed that subjects with SIS have impaired upward and external rotation on affected shoulders during shoulder abduction (Endo et al., 2001). However, it remains controversial whether scapular kinematics are asymmetric in participants with SIS. The findings from Warner's study (Warner et al., 1992) are based on the sample group combined with a part of subjects whom involved shoulders being dominant. Research on healthy shoulders has shown that dominance may have an effect on scapular upward rotation (Matsuki et al., 2012) and posterior tilt (Lee et al., 2013). Thus, quantification of three-dimensional (3-D) scapular kinematics and scapular asymmetry during shoulder elevation and lowering may enable us to enhance our knowledge about scapular behavior in symptomatic shoulders, and may further provide basis for clinical evaluation and biomechanical considerations in shoulder rehabilitation.

Therefore, the primary aim of this study was to compare dynamic 3-D scapular kinematics and scapular asymmetry between participants with SIS and healthy controls. The secondary aim was to investigate the side-to-side differences in scapular kinematics for both participants with SIS who have been suffering from unilateral shoulder pain at the dominant arm and healthy controls during shoulder elevation and lowering. We hypothesized that when compared with healthy controls, participants with SIS would show altered scapular kinematics and more scapular asymmetry. Additionally, side-to-side differences in kinematics would appear for both participants with SIS and healthy controls.

2. Methods

The Institutional Review Board approved the protocol for this study, and all participants were informed of the nature of the study and signed a consent form.

2.1. Participants

A total of 66 participants including participants with SIS ($n = 29$) and healthy controls ($n = 37$) participated in the study. Healthy controls were selected from asymptomatic volunteers who had no history of shoulder pain or injury related to upper body and extremities. These participants did not have a positive Neer (Neer, 1983), Hawkins-Kennedy (Hawkins and Kennedy, 1980) or apprehension-relocation test (Tzannes et al., 2004). Symptomatic participants, who were diagnosed with SIS by a consulting orthopedic surgeon, must have been suffering from unilateral shoulder pain at the dominant arm lasting more than six weeks. To be able to determine if a participant is right-handed, left-handed or ambivalent, all the participants were interviewed regarding the hand preference for various daily activities (writing, brushing teeth, cutting, etc.). Participants with SIS were enrolled in this trial according to clinical examination were positive for at least two of the following; (1) painful arc during flexion or abduction, (2) Neer test (Neer, 1983) or Hawkins-Kennedy (Hawkins and Kennedy, 1980) test, and (3) painful resisted external rotation, abduction or painful Jobe's test (Magee, 1997). Excluded from this study were patients with a history of traumatic onset, existence of massive rotator cuff tears, long head of biceps tendon tears, or degenerative joint disorders at the shoulder complex. Also, the inclusion criteria for participation for all participants were no limitation in shoulder range of motion and no prior shoulder surgery. Participants were excluded if they had any known systemic, neurological disorders or rheumatological disorders including cervical radiculopathy, and who performed repetitive overhead shoulder movements related to occupation or sports activities on a regular basis, or had a body mass index higher than 30 kg/m^2.

2.2. Instrumentation

3-D kinematic data were collected with a Flock of Birds electromagnetic tracking device (Ascension Technology Corporation, Shelburne, VT). This system comprises of an electronics unit, standard-range transmitter, five sensors, and one digitizer, interfaced with the Motion Monitor software program (Innovative Sports Training, Inc., Chicago, IL). Data collected with this electromagnetic tracking system are reliable, with previously reported trial-to-trial, within-day, without-removal-of-sensors correlation coefficient values ranging between 0.88 and 0.97 and standard error of measurement values ranging from 1.35° to 1.74° (Thigpen et al., 2005). Data collected with this electromagnetic tracking system have validated when humerothoracic elevation is below 120° (Karduna et al., 2001).

2.3. Experimental procedure

For data collection, five sensors were attached directly to the skin with double-sided adhesive tape and further secured with nonelastic tape. The thoracic sensor was located over the T1 spinous process, the two scapular sensors were applied to each scapula over the flattest aspect of the postero-lateral aspect of the acromion and the two humeral sensors for each arm were applied over the posterior aspect of the humerus distal to the triceps muscle belly bilaterally. Participants stood with their arms relaxed while specific bony landmarks on the thorax (C7, T8, jugular notch, xyphoid process), scapula (trigonum spine scapula, inferior angle, posterior acromial angle, coracoid process), and humerus (lateral and medial epicondyle) were digitized to create an anatomically based local coordinate system.

All participants were asked to perform bilateral, full shoulder flexion. Verbal comments were made to keep thumbs pointing upward and maintain straight elbow position during recording. Participants performed three repetitions of full overhead arm elevation using two portable wooden poles as a guide for sagittal plane, at a speed matching the beat of a metronome set at 60 beats per minute, using three seconds for elevation and three seconds for lowering.

2.4. Data analysis

The method suggested by Meskers et al. (Meskers et al., 1998) was used to define the rotation center of the glenohumeral joint. The International Society of Biomechanics standard protocol was followed to define segmental axes and convert the local coordinate system into angular rotations using the Euler angle sequence (Wu et al., 2005). Scapular rotations were represented using the y-x'-z" sequence, in which the first rotation defined the amount of internal-external rotation, second upward-downward rotation, and last anterior–posterior tilt. Humeral rotations were represented using the y-x'-y" sequence of humerothoracic elevation, in which the first rotation defined the plane of elevation, the second defined the amount of humerothoracic elevation, and the third the amount of axial rotation. Data for scapular orientation at 30°, 60°, 90°, and 120° of humerothoracic elevation and lowering were obtained for each repetition. The scapular orientation values at each humerothoracic elevation angle were averaged across the three repetitions.

The method suggested by Zifchock et al. (Zifchock et al., 2008) was used to defined symmetry angle (SA), to be able to quantify scapular asymmetry throughout shoulder flexion between involved and noninvolved shoulders of participants with SIS or dominant and nondominant shoulders of healthy controls. This method is reported as an effective quantification of asymmetry for gait analysis and recommended preferable over the symmetry index which is prone to normalization problems (Zifchock et al., 2008). The SA is a measure related to the angle formed when a dominant or involved side value is plotted against a nondominant or noninvolved side value: (*Xdominant or involved, Xnondominant or noninvolved*). The SA values were calculated from the data for each scapular kinematics variable identified previously at the same humerothoracic elevation angle using formulae:

(1) If (45° - arctan (*Xnondominant or noninvolved/Xdominant or involved*) < 90°, the following equation was substituted: $SA = \frac{(45° - \arctan(Xnondominantornoninvolved/Xdominantorinvolved))}{90°} \times 100\%$.

(2) If (45° - arctan (*Xnondominant or noninvolved/Xdominant or involved*) > 90°, the following equation was substituted:

$$SA = \frac{(45° - arctan(Xnondominantornoninvolved/Xnondominantornoninvolved) - 180°)}{90°} \times 100\%$$

The SA value of 0% indicates perfect symmetry, while 100% indicates that the two values are equal and opposite in magnitude.

2.5. Statistical analysis

Statistical analysis of kinematic data was performed using two-way analysis of variance (group-by-angle) with group as the between-subjects factor and angle (humerothoracic elevation angle; 30°, 60°, 90°, 120° of elevation and 120°, 90°, 60°, 30° of lowering) as the repeated factor to compare kinematics between participants with SIS and healthy controls. When significant interactions were found, pairwise t-tests were conducted to compare groups at specific angles of humerothoracic motion. Also, another two-way analysis of variance (side-by-angle) with the factors of side (involved versus noninvolved for participants with SIS; dominant versus nondominant for healthy controls) and angle (humerothoracic elevation angle; 30°, 60°, 90°, 120° of elevation and 120°, 90°, 60°, 30° of lowering) as the repeated factor to compare side-to-side kinematic differences for both participants with SIS and healthy controls, separately. The Greenhouse–Geisser correction was used to adjust the degrees of freedom when the sphericity assumption was violated. When the interaction term was not significant, the main effect for group or side was evaluated. Comparison of SA was performed using an independent-samples Student's *t*-test to compare scapular asymmetry between participants with SIS and healthy controls. The significance level was set at 0.05.

3. Results

Participants with SIS and healthy controls shared similar baseline characteristics (Table 1.). For the all groups, scapular kinematics while performing shoulder elevation are illustrated in Fig. 1 for internal-external rotation, Fig. 2 for upward-downward rotation, and Fig. 3 for anterior-posterior tilt. In general, although some variations were observed, the scapula moved toward internal rotation, upward rotation, and posterior tilt during shoulder elevation; conversely, the scapula moved toward external rotation, downward rotation and anterior tilt during lowering (Figs. 1 through 3).

Table 1
Characteristics of participants.

	Healthy controls $n = 37$	Subjects with SIS $n = 29$	*p*
Age (years)	24 (1)	26.1 (7.5)	0.09
Body mass index (kg/m^2)	23.2 (2.5)	24.1 (2.9)	0.18
Gender (n)	13 Female	17 Female	0.08
	24 Male	12 Male	
Dominancy (n)	33 Right	23 Right	0.31
	4 Left	6 Left	
Duration of symptoms (months)	N/A	6.4 (5.5)	N/A
Pain severity on VAS (cm)	N/A	5.2 (2.6)	N/A
SPADI score (points)	N/A	46.9 (21.2)	N/A

Note: Data given as mean and standard deviation (for age, body mass index, duration of symptoms, pain and disability), or as counted numbers (gender, dominancy).
VAS; visual analog scale, SPADI; Shoulder Pain and Disability Score.
Exact *p* values based on student-*t*-test for age and body mass index, and Fisher's exact test for gender and dominancy.

3.1. 3-D scapular orientation

3.1.1. Involved shoulder for participants with shoulder impingement syndrome versus dominant shoulder for healthy controls

There was no statistically significant group-by-angle interaction ($F_{1.7,\ 110.7} = 2.96$, $p = 0.06$) or main effect ($F_{1,\ 64} = 2.66$, $p = 0.10$) of group for scapular internal-external rotation (Fig. 1.). There was statistically significant group-by-angle interaction for scapular upward-downward rotation ($F_{1.9,\ 126.4} = 10.37$, $p < 0.001$). Pairwise comparisons indicated that the scapula was more downwardly rotated in participants with SIS at 120° of humerothoracic elevation during the elevation phase ($p = 0.004$; mean difference, 7.2°) and, at 120° ($p = 0.005$; mean difference, 7.7°) and 90° ($p = 0.03$; mean difference, 4.8°) of humerothoracic elevation during the lowering phase (Fig. 2.). There was statistically significant group-by-angle interaction for scapular anterior–posterior tilt ($F_{2.5,\ 162.1} = 4.80$, $p = 0.005$). Pairwise comparisons indicated that the scapula was more anteriorly tilted in participants with SIS at 60° ($p = 0.004$; mean difference 4.7°), 90° ($p = 0.006$; mean difference, 5.1°), 120° ($p = 0.001$; mean difference, 6.7°) of humerothoracic elevation during the elevation phase and; at 120° ($p = 0.005$; mean difference, 5.5°), 90° ($p = 0.01$; mean difference, 4.3°) and 60° ($p = 0.02$; mean difference, 3.6°) of humerothoracic elevation during the lowering phase (Fig. 3).

3.1.2. Noninvolved shoulder for participants with shoulder impingement syndrome versus nondominant shoulder for healthy controls

There was no statistically significant group-by-angle interaction ($F_{1.8,\ 117.7} = 1.52$, $p = 0.22$) for scapular internal-external rotation. However, there was a main effect ($F_{1.8,\ 117.7} = 28.9$, $p < 0.001$; 39.8° for noninvolved shoulder for participants with SIS versus 38.9° for nondominant shoulder for healthy controls) of group for scapular internal-external rotation indicating that, at noninvolved side, the scapula was slightly more internally rotated at all angles of humerothoracic elevation during for both the elevation and lowering phases (Fig. 1). There was statistically significant group-by-angle interaction for scapular upward-downward rotation ($F_{2.4,\ 158.7} = 39.77$, $p < 0.001$). Pairwise comparisons indicated that the scapula was more downwardly rotated at noninvolved shoulder for participants with SIS at 60° ($p = 0.01$; mean difference, 4.1°), 90° ($p < 0.001$; mean difference, 6.6°), and 120° ($p < 0.001$; mean difference, 12.7°) of humerothoracic elevation during the elevation phase and, at 120° ($p < 0.001$; mean difference, 13.6°), 90° ($p < 0.001$; mean difference, 8.3°), and 60° ($p = 0.02$; mean difference, 3.9°) of humerothoracic elevation during the lowering phase (Fig. 2.). There was no statistically significant group-by-angle interaction ($F_{1.7,\ 110.5} = 2.25$, $p = 0.11$) for scapular scapular anterior-posterior tilt. However, there was a main effect ($F_{1.7,\ 110.5} = 33.5$, $p < 0.001$; −12.5° for noninvolved shoulder for participants with SIS versus −11° for nondominant shoulder for healthy controls) of group for scapular anterior-posterior tilt indicating that, at noninvolved side, the scapula was slightly more anteriorly tilted at all angles of humerothoracic elevation during for both the elevation and lowering phases (Fig. 3.).

3.1.3. Side-to-side differences

For participants with SIS; there was no statistically significant side-by-angle interaction for scapular internal-external rotation ($F_{1.9,\ 53.9} = 0.52$, $p = 0.58$), upward-downward rotation ($F_{2.6,\ 73.6} = 2.70$, $p = 0.05$), anterior-posterior tilt ($F_{1.9,\ 55.1} = 0.38$, $p = 0.67$), or main effect of side for scapular internal-external rotation ($F_{1,\ 28} = 0.05$, $p = 0.82$) and upward-downward rotation ($F_{1,\ 28} = 0.01$, $p = 0.91$). However, there was statistically significant main effect of side for scapular anterior-posterior tilt ($F_{1,\ 28} = 7.37$, $p = 0.01$; −15.1° for involved versus −12.5° for noninvolved side) indicating that, at involved side of participants with SIS, the scapula was more anteriorly tilted at all angles of humerothoracic elevation during for both the elevation and lowering phases (Fig. 3).

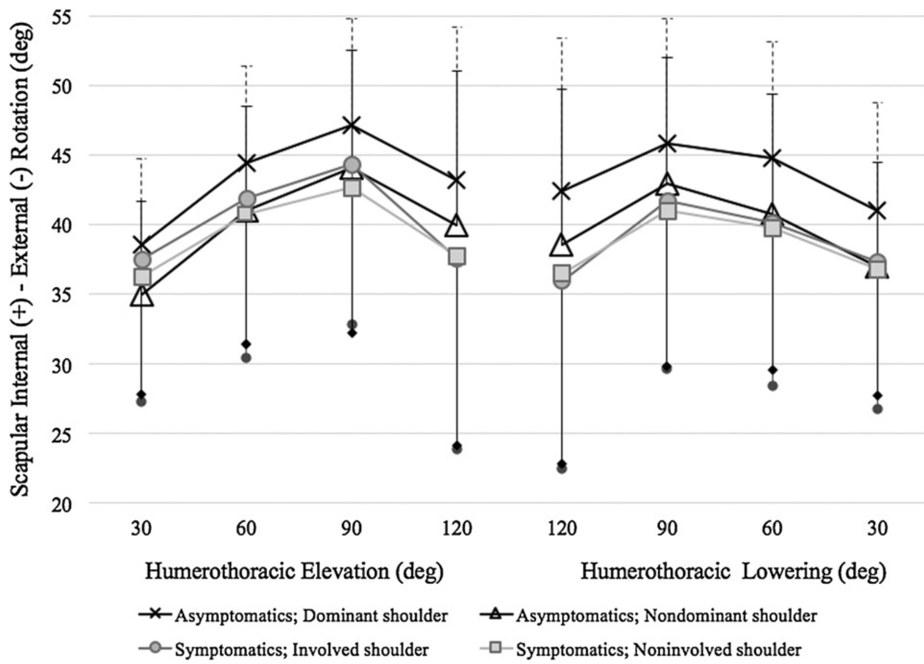

Fig. 1. Scapular internal-external rotation during shoulder elevation and lowering among participants with and without SIS. Note: Data are presented as Mean and Standard Deviation. Deg; degrees.

For healthy controls; there was no statistically significant side-by-angle interaction for scapular internal-external rotation ($F_{1.9,\ 71.4} = 0.50$, $p = 0.61$), upward-downward rotation ($F_{2.05,\ 73.9} = 1.87$, $p = 0.16$), anterior-posterior tilt ($F_{2.3,\ 85.41} = 0.55$, $p = 0.60$), or main effect of side for scapular anterior–posterior tilt ($F_{1,\ 36} = 0.04$, $p = 0.82$). However, there was statistically significant main effect of side for scapular internal-external rotation ($F_{1,\ 36} = 5.67$, $p = 0.02$; 43.4° for dominant versus 39.8° for nondominant side) and scapular upward-downward rotation ($F_{1,\ 36} = 7.45$, $p = 0.01$; −12.7° for dominant versus −15.7° for nondominant side) indicating that, at dominant side of healthy controls, the scapula was more internally (Fig. 1) and downwardly (Fig. 2) rotated at all angles of humerothoracic elevation during for both the elevation and lowering phases.

3.2. Symmetry

Comparisons of SA between participants with SIS and healthy controls at each angle of humerothoracic elevation indicated that the scapular internal-external rotation was more asymmetrical between sides in participants with SIS at 60° ($p = 0.04$; Mean (95% CI); 4.7% (3.3–6.1) for healthy controls versus 8.8% (5–12.5) for participants with SIS) and 90° ($p = 0.03$; 4.9% (3.4–6.5) for healthy controls versus 9.2% (5.6–12.9) for

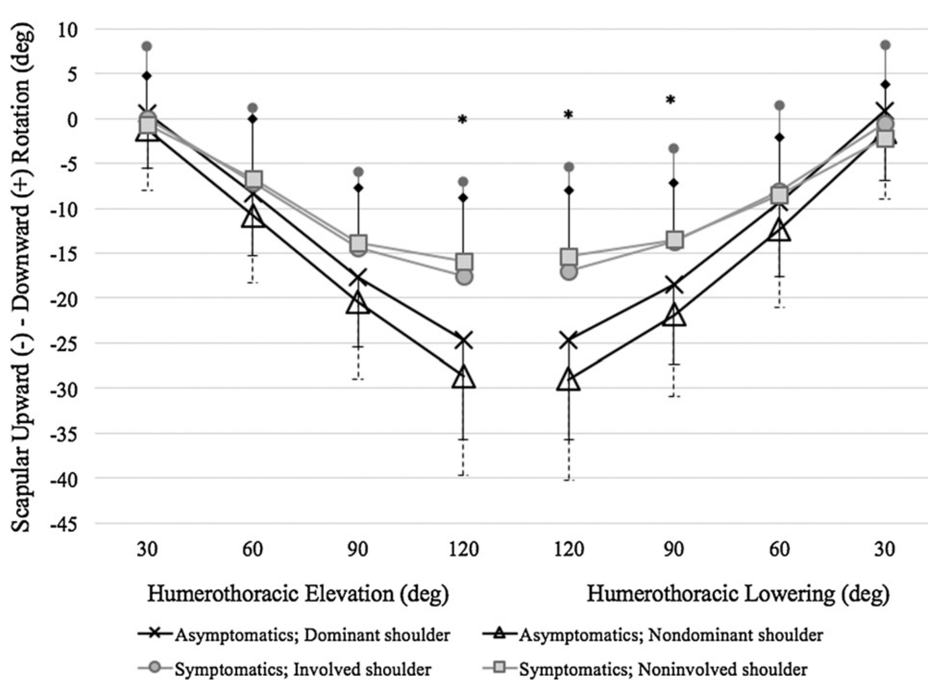

Fig. 2. Scapular upward-downward rotation during shoulder elevation and lowering among participants with and without SIS. Note: Data are presented as Mean and Standard Deviation. Deg; degrees. *Significant difference between groups at this angle ($p < 0.05$).

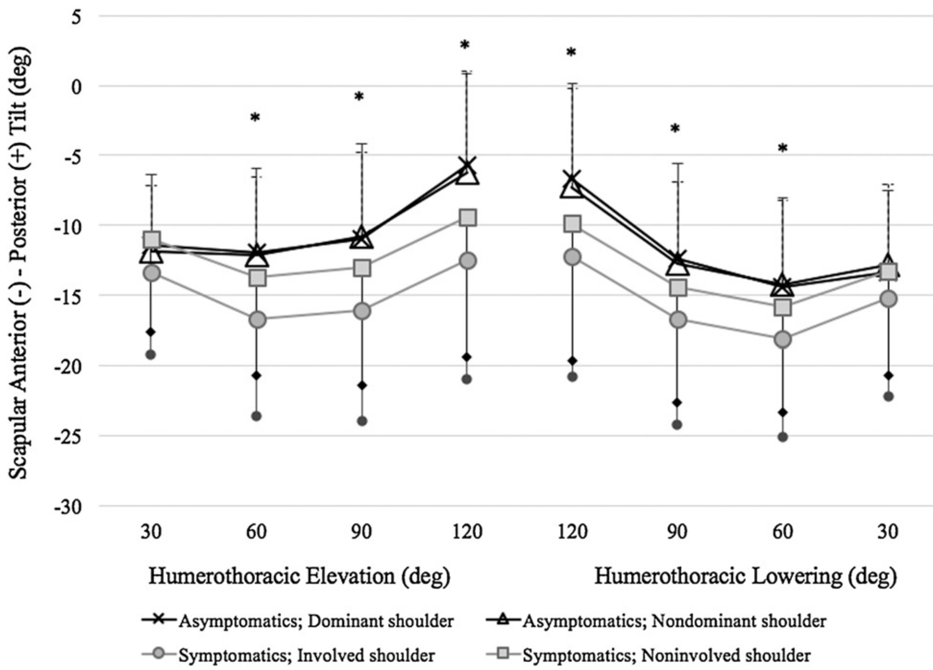

Fig. 3. Scapular anterior-posterior tilt during shoulder elevation and lowering among participants with and without SIS. Note: Data are presented as Mean and Standard Deviation. Deg; degrees. *Significant difference between groups at this angle ($p < 0.05$).

participants with SIS) of humerothoracic elevation during elevation phase (Fig. 4.). Also, comparisons indicated that the scapular upward-downward rotation was more asymmetrical between sides in participants with SIS at 60° ($p = 0.01$; 21.4% (15.2–27.7) for healthy controls versus 35.2% (25.6–44.8) for participants with SIS), and 90° ($p = 0.04$; 10.2% (7.2–13.1) for healthy controls versus 17.4% (10.3–24.5) for participants with SIS) of humerothoracic elevation during elevation phase, and 120° ($p = 0.01$; 9.7% (7.4–12) for healthy controls versus 20.5% (12.4–28.6) for participants with SIS) and 90° ($p = 0.01$; 11.5% (8.1–14.9) for healthy controls versus 24.1% (15.1–33) for participants with SIS) of humerothoracic elevation during lowering phase (Fig. 5.). There were no statistically significant differences for asymmetry in scapular anterior–posterior tilt between participants with SIS and healthy controls ($p > 0.05$; Fig. 6.).

4. Discussion

This study provides information describing the scapular kinematic alterations and scapular asymmetry in participants with SIS who have been suffering from unilateral shoulder pain at their dominant arm.

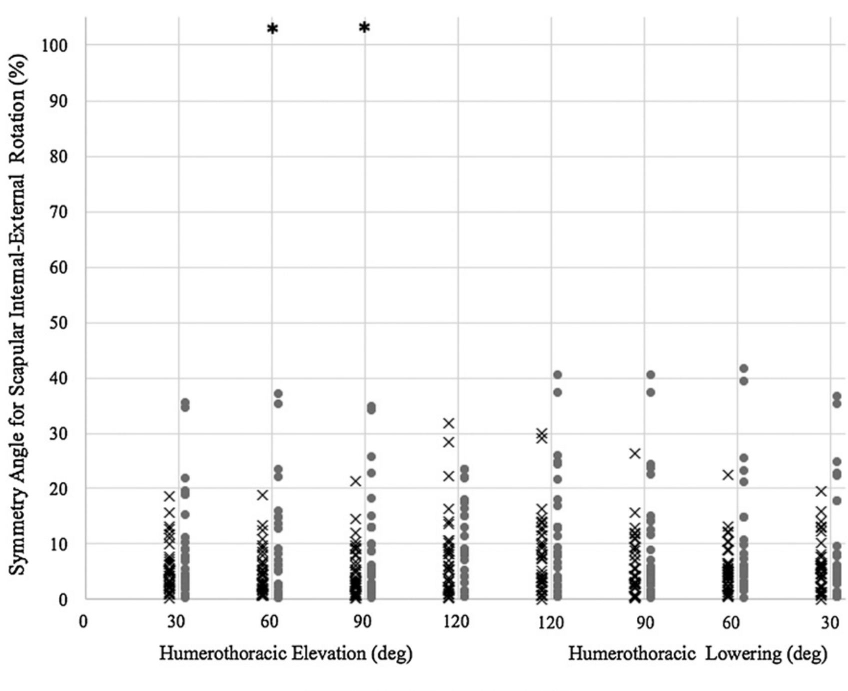

Fig. 4. Symmetry Angle for scapular internal-external rotation during shoulder elevation and lowering among participants with and without SIS. Note: Each point on the figure represents an individual participant. Deg; degrees. *Significant difference between groups at this angle ($p < 0.05$).

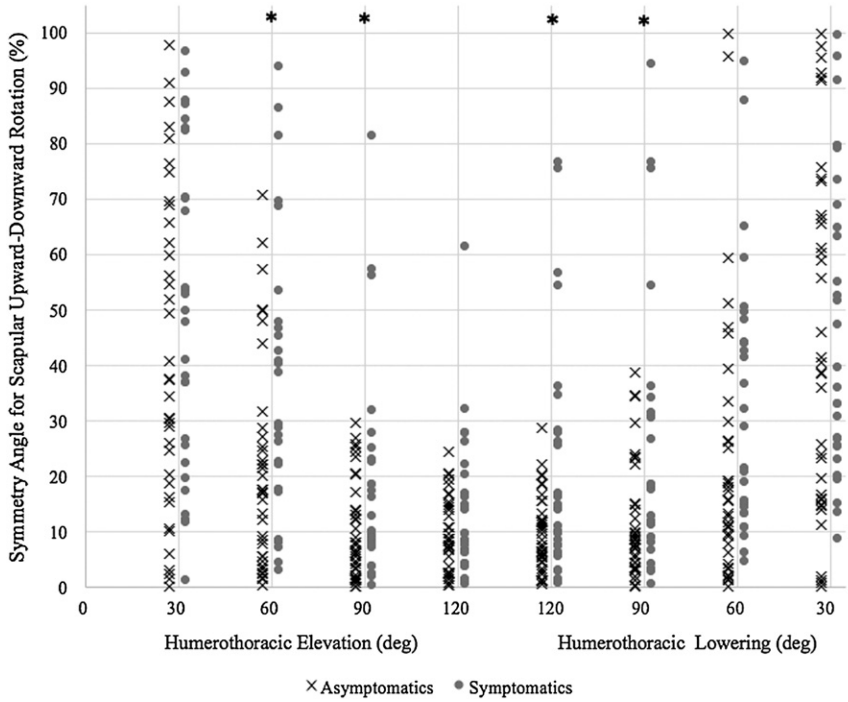

Fig. 5. Symmetry Angle for scapular upward-downward rotation during shoulder elevation and lowering among participants with and without SIS. Note: Each point on the figure represents an individual participant. Deg; degrees.*Significant difference between groups at this angle ($p < 0.05$).

We found that the scapula was more downwardly rotated and anteriorly tilted in participants with SIS compared to healthy controls. In addition, the findings of this study provide information describing side-to-side scapular kinematic differences and asymmetry for both participants with SIS and healthy controls. We found that there were side-to-side differences in both groups; however, the scapular movement was more asymmetrical for scapular internal and upward rotation in participants with SIS compared to healthy controls.

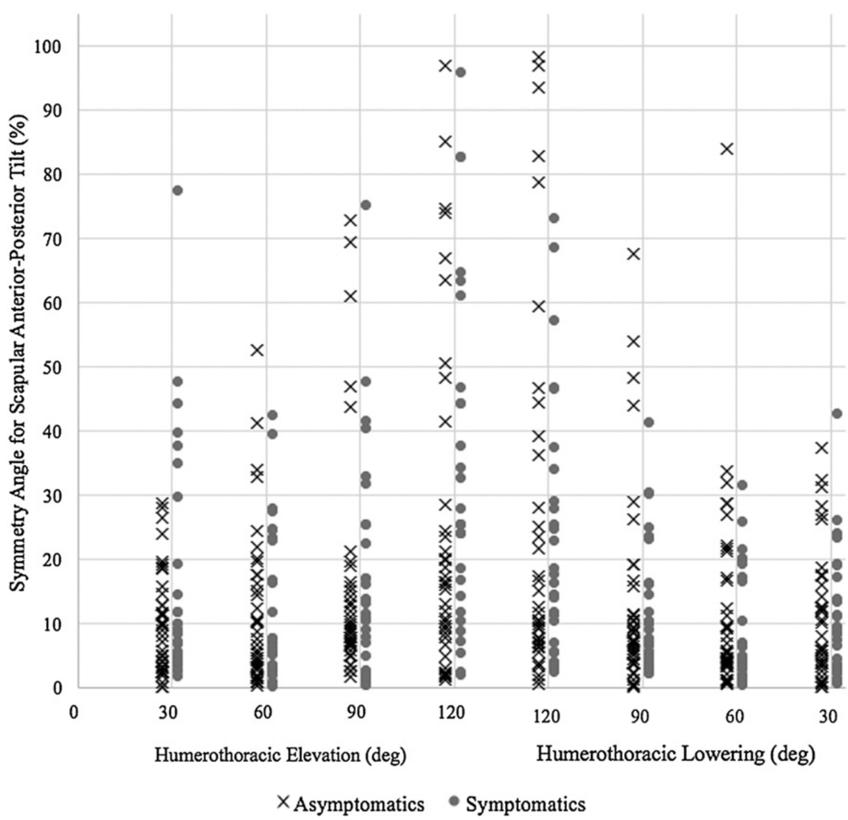

Fig. 6. Symmetry Angle for scapular anterior–posterior tilt during shoulder elevation and lowering among participants with and without SIS. Note: Each point on the figure represents an individual participant. Deg; degrees.

There are several possible mechanisms that may result in scapular kinematic alterations, such as altered scapular muscle activation, soft tissue tightness, or posture (Ludewig and Reynolds, 2009). One or many of these factors may be involved in the SIS syndrome (Ludewig and Reynolds, 2009). Our findings showed that the scapular kinematic differences between study groups reached 7.7° for upward rotation and 6.7° for posterior tilt. Similar to the majority of previous research, the scapula was more downwardly rotated and anteriorly tilted in individuals with SIS; in contrast, other previous research using a similar data collection method have reported differences in upward rotation, which was <5°, or in anterior tilt, which was <5.8° (Ludewig and Cook, 2000; McClure et al., 2006). Contrary to these studies, in this study, participants were excluded if they had acute shoulder pain (less than six weeks). Pain existence may further change muscle recruitment patterns and strategies for motor control, thus resulting in more obvious differences of magnitude (Falla et al., 2004; Hodges and Richardson, 1999).

An electromyography study (Wadsworth and Bullock-Saxton, 1997) reported that muscle latency properties of middle and lower serratus anterior appeared bilaterally delayed in participants with unilateral impingement symptoms. Similarly, our findings support the idea that individuals with unilateral shoulder pain may have altered bilateral kinematics. In the current study, for participants with subacromial impingement syndrome, the scapula was slightly more anteriorly tilt when comparing the involved and noninvolved side. The side-to-side difference in angular data may be clinically small and under the minimal detectable change value in magnitude (up to 2.6°); however, symptomatic shoulders still reveal more asymmetry for scapular position at specific humerothoracic elevations. While assessing the patients clinically, special attention should be paid to scapular asymmetry, especially for scapular internal rotation and downward rotation, which may manifest as scapular winging, at middle ranges of humerothoracic elevation (60°–90°) and at higher ranges (120°–90°) of lowering.

In asymptomatic shoulders, the scapula was upwardly rotated in a linear fashion, externally rotated, and posteriorly tilted nonlinearly during humeral elevation. The scapular external rotation and posterior tilt more obviously occurred around 90° of arm elevation. Although previous studies have compared dynamic kinematics in the dominant and non-dominant shoulder, it was controversial whether scapular kinematics are symmetric (Matsuki et al., 2011; Oyama et al., 2008; Uhl et al., 2009; Warner et al., 1992; Yoshizaki et al., 2009). Our findings show that the scapula on the dominant side was more internally rotated and anteriorly tilted during humeral elevation and lowering. While the magnitude of the differences was relatively small (up to 3.6°), our findings correspond to other studies suggesting that the scapular movement is not symmetric in asymptomatic shoulders. However, this novel method for describing scapular asymmetry using SA provides comprehensive information during dynamic humeral elevation. Surprisingly, the calculation of SA indicated that asymptomatic participants might have scapular asymmetry during early stages of humeral elevation, especially in upward rotation, and during late stages of humeral elevation in posterior tilt. Scapular asymmetry to a certain extent (the upper bound of 95% confidence interval of SA was up to 27.7%) may not contribute to clinical symptoms.

There are some limitations of this study. First, the findings of this study only apply to a very specific subgroup of young to middle-aged adults who mild SIS symptoms; thus, are not applicable to subjects who have more chronic or severe symptoms. Although repetitive overhead activities have been implicated as etiological factors in glenohumeral instability and SIS (Cohen and Williams Jr., 1998), in this study, we have excluded the participants who had contributing repetitive overhead shoulder movements related to occupation or sports activities on a regular basis from both symptomatic and asymptomatic groups, because overhead shoulder activities such as throwing might result in adaptive changes around shoulder complex (Borsa et al., 2008). Considering the multifactorial etiology of the SIS, one or more of the following factors such as existence of scapular dyskinesis, postural problems, glenohumeral laxity, flexibility deficits may contribute to the symptoms for participants with SIS. Second, the 3-D kinematic data were only presented in a range from 30° to 120° of humerothoracic elevation and in the sagittal plane humeral movement. We have considered collecting kinematic data using electromagnetic tracking device because previously it was suggested that sagittal plane recordings can be more validated option (Haik et al., 2014; Thigpen et al., 2005). On the other hand, Timmons et al. (Timmons et al., 2012) reported that the scapular plane is most likely to demonstrate altered kinematics in patients with SIS. Furthermore, motions in the scapular plane are much more functional. Therefore, the unique nature of plane specific scapular kinematics leads us to suggest that further studies are required in other planes of motion to provide greater insight into the effects of SIS within the ranges more commonly used for activities of daily living.

5. Conclusions

In conclusion, in individuals with SIS, the scapula demonstrates greater downward rotation and anterior tilt when compared to healthy controls. Although there were side-to-side differences observed for both symptomatic and asymptomatic participants, there was more scapula asymmetry found in participants with SIS. Restoring altered kinematics and managing scapular asymmetry may be accepted as one of the goals of shoulder rehabilitation in individuals with SIS. The findings of the study increase our knowledge and understanding of scapular alterations in participants with SIS and healthy controls, creating biomechanical considerations for shoulder assessment and rehabilitation.

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