Real-time visual feedback can be used to activate scapular upward rotators in people with scapular winging: an experimental study

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Introduction


Scapular winging is a specific type of scapular dysfunction that has two common causes. One is the denervation of the long thoracic nerve leading to difficulty flexing the shoulder actively above 120°. The second cause is weakness of the serratus anterior muscle. Serratus anterior is one of the prime muscles used to rotate the scapula upward (Dvir and Berme 1978), and weakness of serratus anterior is a major cause of shoulder pain, glenohumeral joint impingement, and winging of the scapula (Ludewig and Cook 2000, Lukasiewicz et al 1999). In particular, over-activation of the upper trapezius and reduced activity in the lower trapezius and serratus anterior muscles during shoulder flexion may contribute to abnormal scapulohumeral rhythm and scapular winging (Cools et al 2004, Cools et al 2007, Ludewig and Cook 2000). Kendall and colleagues (1993) and Sahrmann (2002) also emphasise weakness of serratus anterior as an etiological factor for aberrant scapular mechanics.

Several pushup and wall sliding exercises have been developed for rehabilitation and in the sports field to activate serratus anterior (Hardwick et al 2006, Ludewig and Cook 2004). However, because the scapula is located behind the rib cage, it is not possible for the patient to monitor scapular movement visually during these exercises. Thus, for effective training of serratus anterior, the exercise must be supervised to ensure that the load applied to the upper limb is appropriate and does not cause scapular winging.

To our knowledge, none of the studies that have investigated exercises to strengthen serratus anterior in people with scapular winging have used real-time visual feedback with a video camera to monitor scapular movement during shoulder flexion exercise. We hypothesised that real-time visual feedback would enable neurologically intact people with scapular winging to activate the scapular upward rotators, particularly the serratus anterior muscle, during...
shoulder flexion. Therefore the specific research question for this study was:

Can real-time visual feedback using a video camera facilitate activation of serratus anterior in people with scapular winging during shoulder flexion?

Method

Design

A within-participant, repeated measures experimental study of shoulder muscle activation and scapular alignment was carried out in people with scapular winging as they performed isometric shoulder flexion with and without visual feedback. Electrodes for electromyography were applied over serratus anterior and upper and lower trapezius. Scapular winging was measured with a scapulometer. Initially, scapular winging was measured in a neutral shoulder position. Participants then flexed their shoulder isometrically at 60° and 90°, during which muscle activity and scapular winging were measured.

Participants

Participants were recruited from the Department of Physical Therapy, Yonsei University, Korea. A physical examination was carried out to determine subject eligibility. Adults were eligible to participate in the study if they had weakness of serratus anterior and scapular winging. Weakness of serratus anterior was confirmed by a grade of ‘fair minus’ or lower on manual muscle testing (Hislop and Montgomery 1995). Scapular winging was confirmed by a distance of at least 2 cm between the thoracic wall and the inferior angle of the scapula, measured using a scapulometer – described in detail below. The exclusion criteria were past or present musculoskeletal conditions affecting the cervical or thoracic spine, glenohumeral joint, rotator cuff muscles, or acromioclavicular joints, as well as neurological and cardiopulmonary disorders that could interfere with shoulder flexion.

The scapulometer was modified from the Perry Tool, developed by Plafcan and colleagues (1997). The Perry Tool measures the angle between the transverse plane and a line joining the spinous process and the inferior angle of the scapula, measured using a scapulometer – described in detail below. The exclusion criteria were past or present musculoskeletal conditions affecting the cervical or thoracic spine, glenohumeral joint, rotator cuff muscles, or acromioclavicular joints, as well as neurological and cardiopulmonary disorders that could interfere with shoulder flexion.

The body of the scapulometer is a vertical board 20 cm high with an upper width of 14 cm and a lower width of 11 cm, and a thickness of 1.8 cm. Circular pads (2 cm in diameter and 2 cm high) near each corner of the scapulometer allow it to be applied comfortably to the posterior wall of the thorax. A handle on the opposite surface of the scapulometer allows it to be held in place easily. Extending posteriorly from the superior edge of the scapulometer body is a fixed board, mounted with two parallel guides, which allow a horizontal sliding board to move anteroposteriorly between them (Figure 1).

To measure scapular winging, the examiner stands behind the patient and places the four pads of the scapulometer on the posterior thoracic wall medial to the vertebral border of the scapula, with the sliding board at the level of the inferior angle of the scapula. Holding the scapulometer in place with one hand, the examiner moves the sliding board anteriorly until it touches the inferior angle of the scapula. A ruler on the fixed board measures the posterior displacement of the inferior angle of the scapula from the thoracic wall (Figure 2).

Several methods could be used to elicit scapular winging for measurement, such as applying a load to the patient’s flexed shoulder. Even if the amount of shoulder flexion was fixed, however, the position of the inferior angle of the scapula would vary according to the strength of the upward rotators of the scapula and the scapulohumeral movement pattern. A further problem with this method in the present study would be the inability of the participants to maintain a stable position of shoulder flexion, due to weakness of serratus anterior. We therefore positioned participants in standing with the shoulder in the neutral position, the elbow flexed at 90°, and the forearm in neutral rotation. A cuff weighing 5% of the patient’s body weight was placed on the wrist (Figure 3). In this position, a wrist weight provides a load in a direction that tends to induce scapular winging, tilting, and depression. Participants were advised to keep their hand relaxed in a loose fist because hand activity increases shoulder girdle muscle activity (Sporrong et al 1998).

Before the study commenced, the test-retest reliability of this method of measuring scapular winging was examined.
in 10 people over five days. The interclass correlation coefficient (ICC 2,1) was 0.97 (95% CI 0.87 to 0.99). The standard error of the measurement was 0.1 cm.

**Intervention**

Each participant was seated on a chair with the cervical spine in a neutral position. Participants were asked to flex the affected shoulder to two angles (60º and 90º), either with or without real-time visual feedback. The order of the two angles and the two feedback conditions were randomised by drawing a sealed envelope from a box.

Participants were instructed to lift the upper limb being tested slowly with the elbow extended, the forearm and wrist in a neutral position, and a loose fist, and to hold the position for 5 sec at the flexion angle of 60º or 90º. A universal goniometer was used to determine the flexion angle, and a horizontal target bar was positioned at each angle in the sagittal plane. The shoulder level and scapular movement in the lateral and posterior view were recorded on two video cameras connected to a personal computer. The computer screen was positioned at the participant's eye level and turned on when real-time visual feedback was required.

Before the shoulder flexion, the principal investigator placed the scapula in the normal position (vertebral border parallel with spine spacing at approximately 7 cm, scapula positioned between T2 and T7 and flat on the posterior rib cage). The subject was asked to observe the scapular motion through the computer monitor (Figure 4). If shoulder depression, tilting, or winging were observed during shoulder flexion, the investigator encouraged the subject to protract and elevate the scapula. Participants practised using the visual feedback to maintain the scapula in a normal position for 15 min. The shoulder flexion task was performed three times. A 3-min rest period was allowed between trials to minimise fatigue.

**Measurement**

The primary measure in the study was muscle activity in the scapular upward rotators. Surface electromyographic data were collected from the upper and lower trapezius and serratus anterior, using a standard data acquisition system. Preparation of the electrode sites involved shaving and cleaning the skin with rubbing alcohol (Cram et al 1998). Disposable silver/silver chloride surface electrodes were positioned at an inter-electrode distance of 2 cm. The reference electrode was attached to the styloid process of the ulna of the upper limb being tested. Electromyographic data were collected for the upper trapezius muscle (using electrodes placed 2 cm lateral to the midpoint of a line drawn between the C7 spinous process and the posterolateral acromion), lower trapezius muscle (placed on an oblique vertical angle with one electrode superior and one inferior to a point 5 cm inferomedial from the root of the spine of the scapula), and the serratus anterior muscle (placed vertically along the midaxillary line at rib levels 6–8) (Cram et al 1998, Nieminen et al 1993). Each pair of electrodes was aligned parallel to the line of underlying muscle fibres. Electromyographic data were sampled at 1000 Hz. The signals were amplified and digitised. A band-pass filter (20–450 Hz) was used. The root mean square was calculated from the raw data using a moving window of 50 msec and was converted to ASCII files for analysis. For normalisation, 5 sec of reference contraction data were recorded while the participant performed three trials of maximal voluntary isometric contraction in the manual muscle testing position for each muscle (Kendall et al 1993). To ensure maximal effort, verbal encouragement was given. To minimise compensation during data collection, subjects were encouraged to maintain the testing position (Boettcher et al 2008). The middle 3 sec of the 5–sec contraction were used for data analysis. The initial 1 sec was excluded to ensure maximal amplitude had been reached, and the final 1 sec was discarded to avoid possible fatigue from sustained maximal muscle contraction (Soderberg and Knutson 2000, Dankaerts et al 2004, Tucker et al 2010). A 3-min rest period was provided between trials. The mean root mean square of the three trials was calculated for each muscle. The electromyographic signals collected during each angle of shoulder flexion were expressed as a percentage of the calculated root mean square of maximal voluntary isometric contraction.
The secondary measure in the study was displacement of the acromion in the frontal and sagittal planes. A reflective marker 14 mm in diameter was placed on the skin at the midpoint of the acromion to measure its displacement in the frontal and sagittal planes during shoulder flexion (Figure 4). The reflective marker was not used for visual feedback, but was used for measuring the displacement of acromion. Two video cameras were placed 1.5 m from the shoulder joint; one was located behind the subject to capture the superior and inferior displacement of the marker in the frontal plane, and the other was placed to the side of the subject to capture the anterior and posterior displacement of the marker in the sagittal plane. Two 30-cm-long wooden rods attached to the side and back of a wooden chair were used as reference points to calibrate the motion analysis system in the frontal and sagittal planes (Figure 5). Video files captured during the shoulder flexion test were used to calculate the displacement of the marker. The distance of the acromion movement was measured from the starting position to the end of the predetermined shoulder flexion position in cm by the video motion analysis system software (Figure 5).

Data analysis

For each combination of flexion angle and feedback condition, the average of the three trials was calculated for the data analysis. A two-factor repeated-measures analysis of variance was used to determine differences in muscle activity and acromion displacement during shoulder flexion (60° and 90°) between the real-time visual-feedback and no-visual-feedback conditions. A value ≤ 0.05 was deemed to be statistically significant. A paired t-test with Bonferroni correction was used (with $p = 0.05/6 = 0.0083$) for the pair-wise comparison in muscle activity and marker displacement in the frontal and sagittal planes for the two feedback conditions.

Table 1. Characteristics of the study participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n = 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), mean (SD)</td>
<td>24 (2)</td>
</tr>
<tr>
<td>Height (cm), mean (SD)</td>
<td>169 (6)</td>
</tr>
<tr>
<td>Weight (kg), mean (SD)</td>
<td>61 (7)</td>
</tr>
<tr>
<td>Gender, n male (%)</td>
<td>10 (53)</td>
</tr>
<tr>
<td>Side of winging, n right (%)</td>
<td>14 (74)</td>
</tr>
</tbody>
</table>

Results

Flow of participants through the study

Nineteen participants were recruited from the Department of Physical Therapy, Yonsei University, Korea. The characteristics of the participants are presented in Table 1. All participants completed all aspects of the testing procedure according to the random allocation of testing conditions.

Muscle activity

For the upper trapezius muscle, the main effects were significant for shoulder flexion angle ($p < 0.001$) and feedback ($p = 0.017$), as was the interaction effect ($p = 0.003$). Visual feedback increased activation of the upper trapezius at both 60° and 90° of shoulder flexion (Table 2). After Bonferroni correction, however, the effect of visual feedback was significant only at the 60° shoulder flexion angle ($p = 0.008$). For the lower trapezius muscle, the main effect for shoulder flexion angle was significant ($p = 0.001$), but neither the main effect for the visual-feedback condition ($p = 0.152$) nor the interaction effect ($p = 0.150$) was significant. The data are presented in Table 2.

Figure 5. Real-time visual feedback using video camera input to the computer monitor.
For the serratus anterior muscle, the main effects were significant for shoulder flexion angle \((p < 0.001)\) and feedback \((p < 0.001)\), as was the interaction effect \((p = 0.045)\). Visual feedback significantly increased activation of serratus anterior at both 60° and 90° of shoulder flexion (Table 2). After Bonferroni correction, the effect of visual feedback remained significant at both 60° and 90° of shoulder flexion \((p < 0.001)\).

### Scapular movement

**Measurement of displacement of the acromial marker in the frontal plane** showed that the average movement was superior for all combinations of flexion angle and feedback \((p < 0.001)\), as was the interaction effect \((p = 0.045)\). Visual feedback significantly increased activation of serratus anterior at both 60° and 90° of shoulder flexion (Table 2). After Bonferroni correction, the effect of visual feedback remained significant at both 60° and 90° of shoulder flexion \((p < 0.001)\).

### Discussion

This study found that muscle activity in all scapular upward rotators increased significantly as the shoulder flexion angle increased and that upper trapezius and serratus anterior muscle activity increased significantly with real-time visual feedback.

The increase in the activity of the upward rotators of the scapula between 60° and 90° of shoulder flexion is similar to the gradual increase in activity of the upper trapezius and serratus anterior muscles during arm abduction (Bagg and Forrest 1986). In that study, the lower trapezius remained relatively inactive until the arm was abducted 90°. The lower trapezius increased its activity – and therefore its contribution to the upward rotation force couple – as the arm was elevated beyond 90°. With increasing abduction, the instantaneous centre of rotation of the scapula moved toward the acromioclavicular joint from the root of the spine of the scapula, lengthening the moment arm of the lower trapezius muscle (Bagg and Forrest 1988). Similarly, in the current study of flexion, the moment arm of the lower trapezius lengthens as the amount of shoulder flexion increases. This is likely to be responsible the significant increase in activity of the lower trapezius at 90° flexion (especially maintaining the isometric contraction).

### Table 2. Mean (SD) muscle activation as a percentage of the maximum voluntary isometric contraction at 60° and 90° shoulder flexion with and without visual feedback, and mean (95% CI) difference between feedback conditions \((n = 19)\).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Shoulder flexion angle</th>
<th>Muscle activation (%MVIC)</th>
<th>p value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Feedback</td>
<td>None</td>
<td>Visual minus None</td>
</tr>
<tr>
<td>Upper trapezius</td>
<td>60°</td>
<td>7.9 (5.4)</td>
<td>5.6 (2.3)</td>
<td>2.3 (0.7 to 4.0)</td>
</tr>
<tr>
<td></td>
<td>90°</td>
<td>8.8 (4.7)</td>
<td>7.5 (2.4)</td>
<td>1.3 (0.0 to 2.5)</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>60°</td>
<td>15.0 (11.4)</td>
<td>14.5 (8.4)</td>
<td>0.4 (–1.7 to 2.6)</td>
</tr>
<tr>
<td></td>
<td>90°</td>
<td>21.0 (18.8)</td>
<td>24.0 (14.8)</td>
<td>–3.0 (–6.8 to 0.7)</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>60°</td>
<td>18.0 (10.4)</td>
<td>15.1 (10.1)</td>
<td>3.0 (2.3 to 3.6)</td>
</tr>
<tr>
<td></td>
<td>90°</td>
<td>31.6 (12.6)</td>
<td>25.7 (13.6)</td>
<td>5.9 (3.3 to 8.5)</td>
</tr>
</tbody>
</table>

\%MVIC = percentage of maximal voluntary isometric contraction

### Table 3. Mean (SD) displacement (cm) of the acromion at 60° and 90° shoulder flexion with and without visual feedback, and mean (95% CI) difference between feedback conditions \((n = 19)\).

<table>
<thead>
<tr>
<th>Direction</th>
<th>Shoulder flexion angle</th>
<th>Displacement (cm)</th>
<th>p value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Feedback</td>
<td>None</td>
<td>Visual minus None</td>
</tr>
<tr>
<td>Superior</td>
<td>60°</td>
<td>3.6 (1.0)</td>
<td>1.5 (0.7)</td>
<td>2.1 (1.4 to 2.7)</td>
</tr>
<tr>
<td></td>
<td>90°</td>
<td>3.6 (0.5)</td>
<td>3.0 (0.9)</td>
<td>0.6 (0.1 to 1.2)</td>
</tr>
<tr>
<td>Anterior</td>
<td>60°</td>
<td>2.5 (1.3)</td>
<td>–0.2 (0.7)</td>
<td>2.7 (1.9 to 3.5)</td>
</tr>
<tr>
<td></td>
<td>90°</td>
<td>2.4 (1.6)</td>
<td>–0.6 (0.9)</td>
<td>3.1 (2.1 to 4.0)</td>
</tr>
</tbody>
</table>

For the serratus anterior muscle, the main effects were significant for shoulder flexion angle \((p < 0.001)\) and feedback \((p < 0.001)\), as was the interaction effect \((p = 0.045)\). Visual feedback significantly increased activation of serratus anterior at both 60° and 90° of shoulder flexion (Table 2). After Bonferroni correction, the effect of visual feedback remained significant at both 60° and 90° of shoulder flexion \((p < 0.001)\).
compared to at 60° flexion. This finding is consistent with the results of other studies investigating muscle activity in the scapular upward rotator muscles during arm elevation (Antony and Keir 2010, Ebaugh et al 2005, Jarholm et al 1991, Mathiassen and Winkel 1990).

Muscle activity in the upper trapezius increased significantly when the participants maintained 60° of shoulder flexion while simultaneously reducing scapular winging using real-time visual feedback. Sahrmann (2002) stated that an increase in upper trapezius activation is needed to compensate for the weakened serratus anterior muscle. Thus the upper trapezius may be supporting the increased activity in the serratus anterior, which was significantly greater at both the 60° and 90° angles when visual feedback was provided. The marker displacement in the frontal plane indicated that scapular elevation increased significantly at the 60° shoulder flexion angle when visual feedback was provided. This may also be the result of the activity of the upper trapezius at the 60° angle. Anterior movement of the acromion in the sagittal plane was significantly greater at both shoulder flexion angles when visual feedback was provided, which is consistent with the increased activity of serratus anterior. These findings indicate that visual feedback helped the participants activate appropriate musculature during shoulder flexion to control scapular winging.

A number of exercises to strengthen serratus anterior have been described in the literature (Decker et al 1999, Ekstrom et al 2003, Hardwick et al 2006, Ludewig et al 2004). These exercises should be performed with scapular protraction to activate the serratus anterior muscle while stabilising the thoracic wall, and they should be carried out with no scapular winging. Sahrmann (2002) suggested that the level of resistance be modified for weakened scapular upward rotators. However, no effective means of self-monitoring and correcting scapular winging during shoulder flexion exercise has been available. Real-time visual feedback using a video provides an immediate and continuous feedback for correcting scapular movement during independent shoulder flexion exercise. Therefore this system of visual feedback is a useful way to facilitate serratus anterior activity during shoulder flexion in people with winging of the scapula.

The activity of the lower trapezius was not significantly increased when visual feedback was provided. This finding may be related to the verbal instructions given to the participants. Participants were instructed to protract and elevate the affected scapula. Thus the verbal instructions may have reinforced the actions of both the serratus anterior and the upper trapezius more than the action of the lower trapezius.

The scapulometer showed high test-retest reliability for the measurement of scapular winging in this study. The scapulometer may be utilised in future research as a screening tool for scapular winging. The threshold of 2 cm was used to define scapular winging in this study because this is the minimum amount of winging of the inferior angle of the scapula we had observed in people with ‘fair minus’ or lower grade of muscle strength of the serratus anterior on manual muscle testing. However, no previous studies have provided normative data for winging or suggested a relationship between the degree of winging and the strength of the serratus anterior muscle. Thus, future studies are warranted to confirm our findings on an objective and reliable grading system and to further investigate the correlation between scapular winging and serratus anterior muscle strength.

The present study had several limitations. First, this was a cross-sectional study, so it could only assess immediate effects. A longitudinal study is warranted to determine the long-term effect of training with visual feedback by people with scapular winging. Also, kinematic data of scapular upward rotation were not collected in this study. Finally, we measured scapular upward rotator muscle activity during isometric shoulder flexion, so the findings of this study cannot necessarily be generalised to concentric or eccentric control of shoulder flexion.

Our findings demonstrate that muscle activity increased in the upper trapezius, lower trapezius, and serratus anterior as the shoulder flexion angle increased under the visual-feedback condition and that the activity in the upper trapezius and serratus anterior muscles was significantly greater than that measured during the no-visual-feedback condition. Thus, visual feedback during shoulder flexion can be recommended to increase activation of the upper trapezius and serratus anterior muscles.


Ethics: The Yonsei University institutional review board approved this study. All participants gave written informed consent before data collection began.

Competing interests: None declared.

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References


Cools AM, Declercq GA, Cambier DC, Mahieu NM, Witvrouw


