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Original article

Motion analysis study of a scapular orientation exercise and subjects' ability to learn the exercise

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Abstract

Exercises to retrain the orientation of the scapula are often used by physiotherapists to optimise shoulder girdle function. The movements and muscle activity required to assume this position have not yet been quantified. Further, patients often find this a difficult exercise to learn accurately, with no data being available on the accuracy of repeated performance. The primary objective of this study was to quantify the movements occurring during a commonly used scapular orientation exercise. The secondary objective was to describe the ability of subjects to learn this position after a brief period of instruction. A group of normal subjects (13 subjects; mean age 32, SD = 9) were taught the scapular orientation exercise. Measurement of the position and muscle actions were made with a motion analysis system and surface electromyography. Further comparison was made of the accuracy of repeated trials. The most consistent movements were upward (mean = 4°, SEM = 0.9°) and posterior rotation (mean = 4°, SEM = 1.6°). All parts of the trapezius muscle demonstrated significant activity in maintaining the position while latissimus dorsi did not. Repeated trials showed that subjects were able to accurately repeat the movement without guidance. The key movements of, and immediate efficacy of a teaching approach for, scapular orientation have been established.

Keywords: Scapula; Motion analysis; Muscle activity; Exercise

1. Introduction

Abnormal scapular movement and muscle function have been shown to be important factors associated with shoulder impingement syndrome (Lukasiewicz et al., 1999; Ludewig and Cook, 2000). Exercises to retrain shoulder function are routinely used by physiotherapists as part of a treatment package for patients with scapular dysfunction (Dickens et al., 2005). One such exercise commonly used is teaching scapular orientation with the arm by the side (Mottram, 1997, 2003). The movements and muscle activity required to assume this position have not yet been quantified.

The primary objective of this study was to quantify the movements occurring during a scapular orientation exercise (SOE) and normal subjects' ability to reproduce the position. The secondary objective was to measure the activity in specific muscles in maintaining this movement, particularly the components of the trapezius muscle.

2. The scapular orientation exercise

The SOE or previously described as scapula setting (Mottram, 1997, 2003) is taught by physiotherapists in a variety of postures, initially with the arm by the side. It has been described as dynamic orientation of the scapula in order to optimise the position of the glenoid (Mottram, 1997). It is the scapular neutral (mid range)

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position in which there is minimal support from the passive osteo-ligamentous system with the position being maintained by the myofascial structures. A description of this exercise may be of value to the clinician planning the rehabilitation of scapular movement and is necessary in order to evaluate the relationship of this exercise to what is already known about scapular movement faults. Many clinicians find the SOE difficult to teach. A clear description of, and evaluation of a teaching schedule for, scapular orientation will give clinicians a clearer picture of the movements involved and help them adopt a suitable strategy for retraining.

3. Methods

3.1. Subjects

The Royal National Orthopaedic Hospital Trust ethics committee granted ethical approval and each subject gave written informed consent. Thirteen subjects were recruited (nine females, four male) aged between 18 and 43 (mean 32, SD 9). All subjects were right handed. Subjects with a history of spinal or upper limb problems that had required treatment or time off work, or any known bony abnormality of the spine (such as a fracture or congenital deformity) were excluded.

3.2. Data collection

A motion analysis system, CODA MPX 30 (Charnwood Dynamics, Rothley, UK) was used to collect the motion data. Studies have shown that skin mounted motion sensors are suitable to measure scapula rotation and translation (Johnson and Anderson, 1990; Ludewig and Cook, 2000; Karduna et al., 2001; Lin et al., 2005; Morrissey et al., 2007). The accuracy of all skin-mounted marker-tracking systems is inherently limited but satisfactory for the purposes of this study. The CODA uses active infrared LED markers to measure positions within a $2 \times 2 \times 3\,m^3$ volume. The translational precision of the instrument has been shown to be within 0.5 mm in each direction, while rotational accuracy is within 1°, determined using factory calibration experiments. Marker positions were captured at 100 Hz. Markers were attached to the thorax (T1, T3, T6), the root of the spine of the scapula, scapula inferior angle and posterior-lateral acromion therefore allowing construction of axis systems in line with ISB recommendations (Karduna et al., 2001).

EMG was recorded using a multi-channel EMG system (MA 300 DTU, Motion Lab Systems, Bolton Rouge, LA, USA). Pairs of self-adhesive gelled surface electrodes 1 cm in diameter at 2 cm distance were used. Preamplifiers were mounted directly over these electrodes and a reference electrode placed over the contra-lateral acromion. EMG was recorded within a bandwidth of 0.2–5.0 kHz and integrated over 5 ms intervals. The resultant values were collated on computer by infrared telemetry at 200 Hz interleaved with the operation of the infrared motion analysis system.

The subject was asked to hold the orientated position for 5 s. Records were examined to determine 2 s when the least movement occurred. Scapula position and muscle activity in the orientated position was extracted by the average position or muscle activity during this 2 s period. Scapula movement was defined in relation to the thorax co-ordinate system, using a ZYX Eulerian transform in accordance with ISB recommendations (Karduna et al., 2000). This procedure effectively removed confounding thoracic movement from the results. Translation of the scapula were measured in millimetres and described as lateral (in the frontal plane), ventral (in the sagittal plane) and superior (in the horizontal plane). Rotations of the scapula were measured in degrees and described as upward rotation (in the coronal plane), external rotation (in the transverse plane) and posterior rotation (in the sagittal plane). For movement data, comparison was made between the resting and scapular orientated positions (unassisted). For data pertaining to the accuracy of positioning, comparison was made with the assisted position data (therapist assisting the new scapula positioning).

EMG electrode pairs were attached over the upper trapezius centred 2 cm lateral to the midpoint between the seventh cervical vertebrae and the lateral end of the acromion (Jensen et al., 1993); the middle trapezius on the mid point of a line from the acromion to the end of the spinous process of the seventh cervical vertebra (Guazzelli et al., 1991); the lower trapezius 3 cm lateral to the spine at the level of the inferior angle of the scapula (Cherington, 1968); and finally the latissimus dorsi 4 cm below the inferior angle of the scapula (Basmajian and DeLuca, 1985). The electrode placements were in line with the fibre direction for each muscle.

4. Procedure

The right shoulder was used in each subject. Subjects were seated on a stool with the feet supported and spine in a neutral position. The subject was taught the SOE by an experienced physiotherapist (primary author). The procedure for teaching the SOE in this experiment has been previously described and is described below (Mottram, 1997, 2003).

The SOE position was determined in each individual. In each subject this was judged to be the mid position

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between their available range of upward and downward rotation, external and internal rotation and posterior and anterior rotation (posterior–anterior tilting) of the scapula. The SOE position was established by active movements by the subject assisted by the therapist. The movements required to achieve the SOE (as judged by the therapist) were then explained to the subject and visual, auditory and kinaesthetic cues were used. Different cues were used for different subjects in order to achieve the objective of positioning the scapula actively in the mid neutral region as subjects respond differently to a given cue. Examples of cues included passive/assisted movements into the SOE position, tactile feedback with gentle pressure on the acromion to encourage upward rotation, recognition of a feeling of widening the chest to encourage posterior tilt, demonstration of common wrongly directed movements, demonstration and verbal feedback. The exact instructions given by the therapist were dependent on the judgement of the relaxed position of the scapula, the movement required to achieve the SOE position and the response of the patient to visual, auditory and kinaesthetic cues. A maximum of 5 min was used for the teaching procedure.

A record of EMG activity was made as the subjects raised their arm through 150° in the scapular plane. The arm was raised over a 3 s period and lowered over a 3 s period. This produced a clear burst of activity at all four recording sites. Maximum activity within any 0.1 s interval during this movement was used as the standard for normalisation purposes. The normalisation of EMG activity with reference to recording during another movement has been used in other studies (Hungerford et al., 2003; Lehman et al., 2004). All EMG signals were rectified and then averaged over the 2 s period and then divided by the normalisation standard. At rest, markers were attached to the bony landmarks described above and their position recorded. The experimenter next positioned the subject in the orientated position for remarking of the scapular landmarks as described above (assisted). A maximum of 5 min was required for this. Following a recording in this position the subject returned to the resting position. Immediately following this (within 2 min), motion data recordings were taken while the subject made three further attempts to return to, and hold for 5 s, the scapula orientated position (unassisted). A rest period of 30 s was allowed between these attempts. EMG recording was made on the first unassisted repositioning attempt only. All EMG signals were rectified and then averaged over the 2 s period and then divided by the normalisation standard.

5. Statistical methods

All statistics were performed using Sigma Stat 2 (Jandel Scientific, CA, USA). The distribution of the data was tested for normality using the Kolmogorov–Smirnov test. Specifically, the Pearson correlation analysis was used for repeated movements, *t*-tests were used to derive the *p*-values for the difference between the resting and SOE position and ANOVA for muscle action with Tukey post hoc tests. The level of significance was set at $p < 0.05$.

6. Results

6.1. Scapular position

The most consistent movements in the transition from resting to the orientated position (assisted) were upward and posterior rotation, which differed significantly from the resting position. All translations in each dimension and rotation in the horizontal plane (Table 1) showed no significant difference from the resting position, possibly reflecting a variety of subject resting positions and therefore strategies required to get to the scapular orientated position. The rotations in the sagittal and coronal plane for each subject are shown in Fig. 1.

6.2. Muscle activity

Fig. 2 shows the average EMG activity recorded during a still period of 2 s during which the orientated position was held on the first unassisted return. EMG was expressed relative to the peak activity recorded during arm flexion after the average activity while sitting in a rest position was subtracted.

Table 1
Summary of the mean movements of the scapula from the rest position to the orientated position for 13 subjects

	Translation (mm)			Rotation (°)		
	Lateral	Ventral	Superior	Upward (coronal plane)	External (transverse plane)	Posterior (sagittal plane)
Mean	2.7	−2.5	2.6	4.0	3.1	4.0
SD	10.7	14.8	7.7	3.4	8.4	6.0
SEM	3.0	4.1	2.1	0.9	2.3	1.6
p	0.387	0.551	0.254	0.001	0.208	0.029

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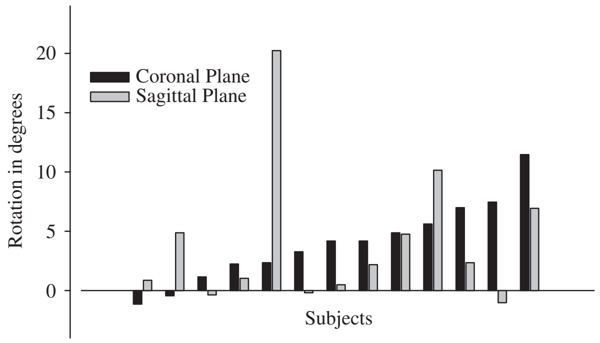

Fig. 1. The rotation of the scapula in the coronal (upward rotation) and sagittal (posterior tilt) planes between the resting and orientated position is shown. Each pair of bars represents the results of the assisted positioning. For the purpose of this figure the subjects are shown in ascending order of the coronal plane rotation needed.

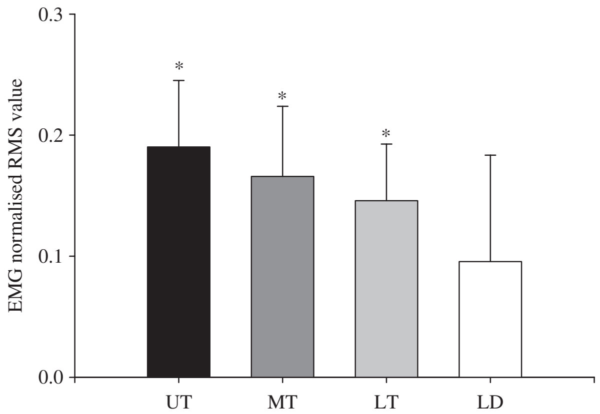

Fig. 2. Mean EMG level during unaided holding of the scapular orientated position for the first unassisted return to the orientated position. The EMG activity, in excess of that during relaxed sitting, is shown on the y-axis relative to that recorded during an arm elevation, as a proportion of the activity recorded during arm elevation. The means which are significantly different from zero are indicated (*$p<0.05$). UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; LD, latissimus dorsi.

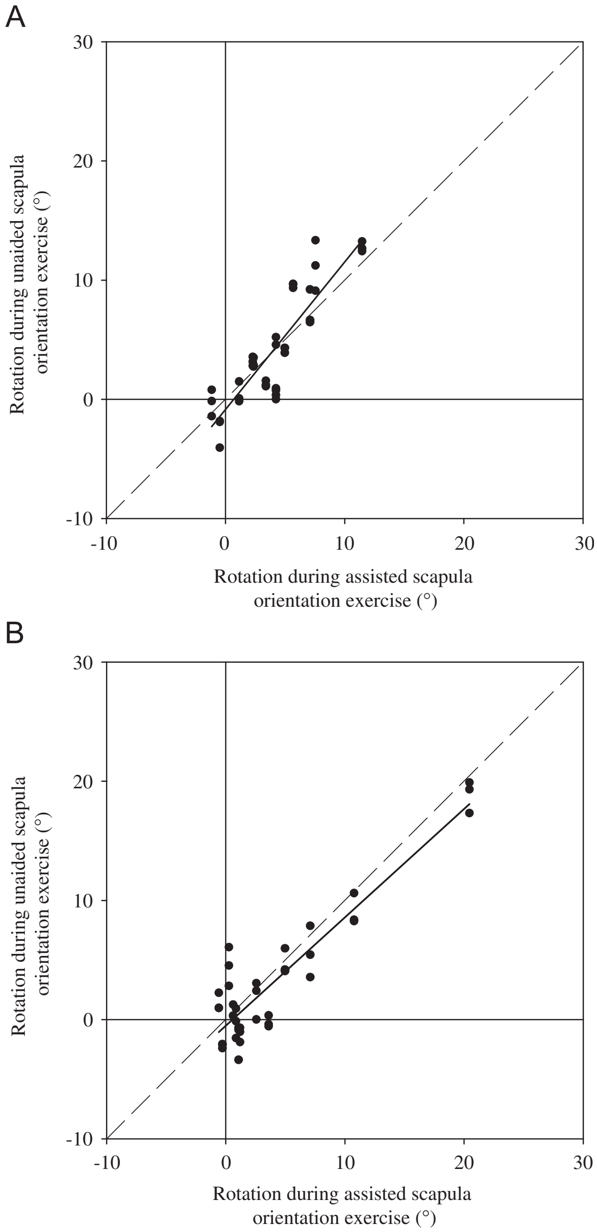

Fig. 3. Comparison of the rotations of the scapula during assisted scapular orientation and unaided return to the orientated in the upper graph A shows the rotations in the coronal plane (upward rotation) and lower graph B shows rotations in the sagittal plane (posterior tilt). There are three trials of return to the orientated position for each subject. The full lines represent the correlation between the datasets while the broken lines are lines of identity.

6.3. Scapular orientation learning

The movements that occurred during an unassisted return to the orientated position were very similar to those that occurred during the assisted movement (Fig. 3). Each of the three tests of unassisted orientated position is shown as a separate point and it can be seen that the points lie close to the line of identity, which would indicate a perfect reproduction of the movement was demonstrated. The correlation between the assisted and unassisted positions are high ($r = 0.919$ and 0.944 for the coronal and sagittal planes, respectively). The correlations between the assisted and unassisted positions were also high (above 0.73, $p<0.01$) for the translations and the horizontal plane rotations even though there was no consistent magnitude of movement for these parameters.

7. Discussion

The results of this experiment show that normal subjects are able to reproduce the SOE position of the scapula within 5 min of being taught. The position was individually determined by taking the mid point of three rotations of the scapula, then employing a range of visual, kinaesthetic and auditory cues in order to facilitate learning. The time scale of position reproduction is especially relevant to physiotherapists treating patients with scapular movement faults as it falls within the usual time available for such teaching. Further, physiotherapists often find it difficult to teach patients the SOE position. It has further significance for physiotherapy educators and mentors teaching novice clinicians who often struggle to teach the SOE. The techniques described here may therefore be useful to physiotherapists seeking to better understand scapular orientation. Further research is needed to determine if subjects with shoulder pain and dysfunction are able to maintain this orientation with the arm by the side both in the immediate and in the long term. The potential for impingement is increased during elevation because the altered scapulo-humeral rhythm may result in the acromion being in closer proximity to the rotator cuff tendons during elevation. The effects of the teaching under loaded conditions and during dynamic/functional movements also need to be addressed.

Subjects consistently required upward rotation and posterior tilt in order to reach the SOE position even though the movements required to reach the SOE position were individually determined. Further, the movements required to reach the SOE position are exactly those that are reduced in patients with impingement syndrome and other shoulder dysfunctions (Lukasiewicz et al., 1999; Ludewig and Cook, 2000; Herbert et al., 2002; Lin et al., 2005). Ludewig and Cook (2000) have suggested rehabilitation of shoulder impingement should consider the rehabilitation of upward rotation and posterior tilt of the scapula based on observed movement deficits in symptomatic subjects.

Abnormal positioning of the scapula with the arm by the side has also been associated with shoulder pain and pathology. Kibler (1998) described excessive anterior tilt of the shoulder with the arm by the side that can affect the positioning of the scapula, leading to impingement and dysfunction. Additionally, there is evidence that pectoralis minor muscle length, measured with the arm by the side, can influence scapula kinematics and decrease scapula posterior tilting during elevation (Borstad and Ludewig, 2005; Borstad, 2006). The movements used in reaching the SOE position are therefore congruent with the recent findings pertaining to shoulder movement patterns seen in patients with impingement pathology.

The activity in four muscles during maintenance of the SOE position was also measured in these normal subjects during the assisted manoeuvre with reference to the amount of activity used to elevate the arm. This showed that all parts of the trapezius were active in maintaining the SOE position while latissimus dorsi was not. Consideration of retraining these muscles may be appropriate in subjects unable to maintain the SOE position. This SOE involves a significant coordinated recruitment of all portions of the trapezius muscle. Johnson et al. (1994) have suggested the role of middle and upper trapezius is to rotate the clavicle about the sterno-clavicular joint. This action will resist downward rotation of the scapula, while mid and lower trapezius may serve to resist anterior tilting. This co-ordinated recruitment may help to maintain optimum orientation. No previous study has measured EMG activity of this exercise so it is not possible to compare results. There are other muscles, which may be involved, e.g. serratus anterior and further research is needed in this area. Ludewig and Cook (2000) and Lin et al. (2005) have described a decrease in serratus anterior muscular activity in subjects with shoulder impingement.

There were some limitations of this study that need to be considered when interpreting the results. Firstly, the sample was a small group of normal subjects without pain who may therefore differ from samples of subjects with shoulder pathology. Nonetheless, this study provides a baseline from which future measurements can be interpreted. Secondly, the measurement procedure may be subject to error as the errors in detection of translation and rotation using the CODA system (0.5 mm and 1°, respectively) may have had an impact on the results. Further there is inherent error in the application of skin-mounted markers for scapular movement measurement, although satisfactory for the purposes of this study (Morrissey et al., 2007). Any errors could be assumed to be consistent between assisted and unassisted SOE position reproduction. Finally, there is the possibility that crosstalk between the sections of trapezius measured may have affected the EMG results for the upper and middle fibres of trapezius. Further work needs to establish agreement on the electrode placement for the different parts of trapezius particularly mid.

8. Conclusion

The SOE has been defined in normal subjects. This paper demonstrates that it is possible to teach a normal subject to consistently reproduce an unfamiliar movement pattern. The experiment highlights how a trained physiotherapist can influence the position of the scapula in terms of upward rotation and posterior tilting which is believed to be important in the rehabilitation of shoulder dysfunction and control of scapula neutral. All three portions of the trapezius muscle were active whilst maintaining the SOE position. This study has implications for physiotherapists seeking improved understanding of the biomechanics involved in an SOE.

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