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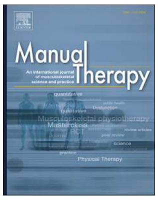

Original article

Alterations of scapular kinematics and associated muscle activation specific to symptomatic dyskinesis type after conscious control

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ABSTRACT

Background: Scapular orientation and movements can affect the function of the shoulder. However, evidence is limited on whether symptomatic subjects can actively maintain the scapula in a neutral position through conscious control.
Objective: To investigate whether symptomatic subjects with scapular dyskinesis can achieve optimal scapular movements and associated muscle activities through conscious control.
Design: A cross-sectional study.
Methods: Sixty subjects with scapular dyskinesis (16 inferior angle pattern I, 16 medial border pattern II, and 28 mixed pattern) performed 3 selected exercises (arm elevation, side-lying elevation, and side-lying external rotation) with and without conscious control. Three-dimensional electromagnetic motion and electromyography were used to record the scapular kinematics and muscle activation during the exercises.
Results: For scapular kinematics, significant increases in scapular external rotation (4.6 ± 3.2°, $p < 0.0125$) were found with conscious control during arm elevation and side-lying elevation in three groups. Significant increases in activation of the middle and lower trapezius (MT: 4.9 ± 2.4% MVIC; LT: 10.2 ± 6.8% MVIC, $p < 0.0\ 25$) were found with conscious control in 3 exercises among the 3 dyskinesis groups. Increased serratus anterior activation (SA: 11.2 ± 4.8% MVIC, $p < 0.0\ 25$) was found in the concentric phase of side-lying external rotation in the pattern I and I + II groups.
Conclusion: Conscious control of the scapula can alter scapular orientation and MT, LT, and SA activation during 3 selected exercises in subjects with symptomatic dyskinesis. Specifically, conscious control during side-lying external rotation can be applied to increase SA activity in pattern I and I + II dyskinesis.

Scapular dyskinesis has been indicated to be related to musculoskeletal disorders of the shoulder complex. Altered scapular positions affect the performance of the rotator cuff significantly (Smith et al., 2002; Kibler et al., 2006; Alizadeh et al., 2009). An inadequately elevated, posteriorly tipped, or upwardly rotated scapula during arm movements may decrease the subacromial space and increase the risk of shoulder impingement (Ludewig and Cook, 2000; Kibler and Sciascia, 2010). Thus, for symptomatic subjects with scapular dyskinesis, it is important to correct scapulothoracic movements (Ludewig and Reynolds, 2009).

Conscious control of the scapula is believed to improve scapular kinematics (Cools et al., 2014). It was first mentioned by Mottram to correct movement dysfunction associated with abnormal scapular positioning and dynamic control. This method can be applied to normalize the scapular resting orientation and promote the proper 3-dimensional movement patterns of the scapula during arm movements. Evidence shows that asymptomatic people with scapular dyskinesis can achieve the corrected scapular position through conscious control of the scapula (Mottram et al., 2009; De Mey et al., 2013).

Appropriate muscle activity during movements, in addition to scapular kinematics, is important to consider for subjects with scapular dyskinesis. Previous studies have reported excessive

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activation of the upper trapezius (UT) and decreased activity of the serratus anterior (SA) and middle/lower trapezius (MT/LT) in subjects with scapular dyskinesis (Ludewig and Cook, 2000; Kibler and McMullen, 2003; Kibler and Sciascia, 2010). Thus, exercise training is focused on correcting the levels of muscle activity. Cools et al. (2007) demonstrated that four exercises, namely, side-lying flexion, side-lying external rotation, prone extension, and prone horizontal abduction with external rotation, have suitable UT/MT and UT/LT ratios in asymptomatic subjects. De Mey et al. (2013) found that conscious control of the scapular orientation combined with these exercises could alter associated muscle activations in asymptomatic subjects with scapular dyskinesis.

Although the effects of conscious control of the scapula have been demonstrated (Cools et al., 2007; Mottram et al., 2009; De Mey et al., 2013), only limited evidence exists to indicate whether symptomatic subjects with scapular dyskinesis can benefit from such control. Furthermore, there are no kinematic findings or subjects classified into different patterns in previous studies (Mottram et al., 2009; De Mey et al., 2013). The purpose of this study was to investigate whether symptomatic subjects with scapular dyskinesis can actively alter scapular orientation and associated muscle activities through conscious control of the scapula. We hypothesized that conscious control could increase scapular external rotation/posterior tipping and increase associated muscle activities in these subjects.

1. Methods

1.1. Subjects

Sixty symptomatic subjects with scapular dyskinesis participated in this study. Subjects were recruited according to the following inclusion criteria: age of 18–60 years old, and unilateral shoulder pain of less than 5 but more than 1 on a 10-point visual analog scale around the shoulder complex, including the glenohumeral joint, scapulothoracic joint, and acromioclavicular joint, during arm movements. Impingement was assessed with palpation of the pain location, speed test, Neer's impingement, Hawkins impingement, and Yergason's test. Exclusion criteria were a history of stroke, diabetes mellitus, rheumatoid arthritis, rotator cuff tear, surgical stabilization of the shoulder, osteoporosis, or malignancies in the shoulder region. Subjects who had pain or disorders of the cervical spine, elbow, wrist, or hand, who had pain radiating from the shoulder to the arm, or who could not elevate their arms to 150° were also excluded. All subjects received a written and verbal explanation of the purposes and procedures of the study.

1.2. Ethical approval statement

Subjects agreed to participate and signed informed consent forms approved by the Human Subjects Committee of University Hospital.

1.3. Instruments

The Polhemus 3Space FASTRAK system (Polhemus Inc., Colchester, VT, USA), an electromagnetic-based motion analysis system, was used for collecting 3-dimensional kinematic data of the scapula. Karduna et al. (2001) validated the scapular kinematics between skin-based sensor and bone-pinned methods and confirmed that the skin-based method is valid when arm elevation is below 120°. The details of the methodology can be found in a previous paper (Lin et al., 2005). Three sensors were placed in locations where the skin motion artifact was minimized (sternum, acromion, distal humerus). Anatomic landmarks (sternal notch, xiphoid process, seventh cervical vertebra, eighth thoracic vertebra, acromioclavicular joint, root of the spine of the scapula, inferior angle of the scapula, lateral epicondyle, and medial epicondyle) were palpated and used for subsequent receiver mounting and landmark digitization.

The sEMG assemblies included pairs of silver chloride circular (recording diameter of 10 mm) surface electrodes (The Ludlow Company LP, Chocopee, MA) with an interelectrode (center-to center) distance of 20 mm, and a Grass AC/DC amplifier (Model 15A12, Astro-Med Inc. RI, USA) with a gain of 1,000, a common mode rejection ratio of 86 dB at 60 Hz, and a bandwidth (−3 dB) of 10 to 1000 Hz. The sEMG data were collected at 1000 Hz/channel using a 16-bit analog to digital converter (Model MP 150, Biopac systems Inc., CA, USA). Surface EMG electrodes were placed on the UT (midway between the acromion and C7), MT (midway between the root of the spine of the scapula and the T3), LT (on the line between the spine of the scapula and the T7) and SA (anterior to the latissimus dorsi and posterior to the pectoralis major) of the involved shoulder. The reference electrode was placed on the ipsilateral clavicle (Huang et al., 2013; Perotto and Delagi, 1994). The maximal voluntary isometric contraction (MVIC) was tested and used to normalize the sEMG data during the task (resisted shoulder flexion 90° for UT, resisted horizontal abduction while lying prone with arm abducted to 90° for MT, resisted arm elevation while lying prone with arm abducted in line with muscle fibers for LT, and resisted arm elevation of 135° for SA) (Ludewig et al., 2004; Kendall and McCreary, 2010). The MVICs were collected for 5 s in a total of three trials, with 1 min of rest between trials.

1.4. Classification of scapular dyskinesis

Visual combined palpation was used to classify the scapular position and movement pattern (single pattern or mixed patterns) in both the raising and the lowering phases, modified by Kibler's method (2010). The 4 single patterns were inferior angle prominence (pattern I), medial border prominence (pattern II), abnormal upward rotation/elevation (pattern III), and normal movement (pattern IV). The mixed patterns were combinations of at least two single patterns. The inter-rater reliability of the classification test was moderate to substantial (κ coefficients = 0.49 and 0.57/0.64 in the raising and lowering phases, respectively) (Huang et al., 2015a,b).

1.5. Conscious control of the scapula

The subjects began the movements, which required achieving a neutral position of the scapula as judged by investigators. Verbal, auditory, and kinesthetic cues were given based on the subjects' resting positions and selected exercise-specific position (side-lying or sitting) with 1 kg load to help them achieve the neutral scapular position. A load with 1 kg was selected because it was the highest load that subject could tolerate without discomfort during the entire experimental procedure. The main instruction, “retract the scapula”, was given to correct poor posture and excessive scapular internal rotation, and a supplemental instruction, “widen the chest”, was given to help subjects achieve a neutral scapular position when scapular posterior tipping was lacking (Mottram et al., 2009). Participants practiced the posture exercise until satisfactory correction, as judged by the investigator, was achieved. Participants who could not correct the scapular posture satisfactorily were excluded from further investigation. Once the subjects could hold the corrected scapular position for 5 s without assistance, they performed the 3 selected exercises (arm elevation in the scapular plane, side-lying flexion, and side-lying external rotation; see Fig. 1) in a randomized order, resting for three minutes before each

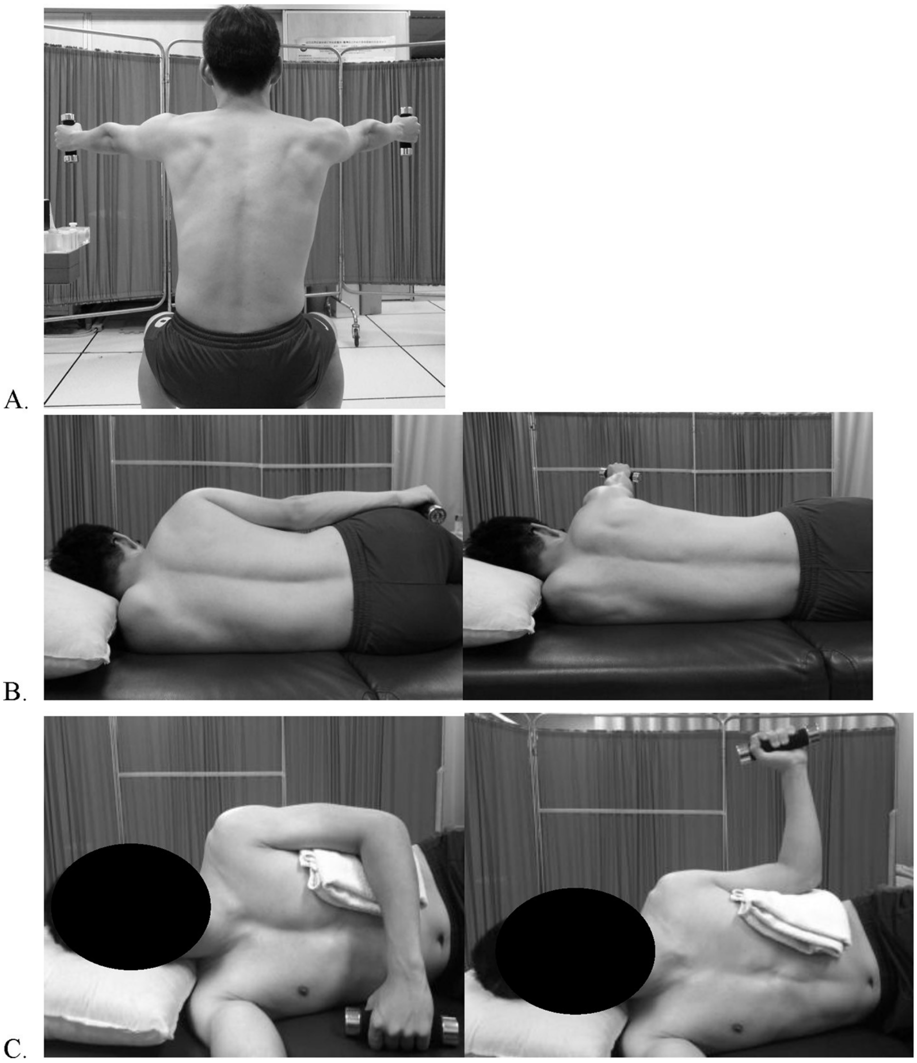

Fig. 1. Illustration of the testing movements. A: arm elevation in scapular plane; B: side-lying elevation; C: side-lying external rotation. A: The subject performed elevation (full range of motion) with the two arms (thumb up with a load) in the scapular plane (30°). A line in the screen was used to guide the phase of elevation in the scapular plane. B. In the starting position, the subject held a load in the hand with the arm by the side and the elbow straight in a side-lying position. The subject performed elevation (full range of motion) with the elbow straight and followed the line on the screen. C. In the starting position, the subject held a load in the hand with the arm resting on a towel on the subject's side and the elbow flexed 90° in a side-lying position. The subject rotated the arm externally without moving the trunk.

subsequent exercise. During the exercise, subjects maintained the corrected orientation for about 3 s and were given appropriate verbal cues in both the concentric and the eccentric phases.

1.6. Outcome measures

The kinematics and sEMG data during arm elevation in the scapular plane and 2 selected exercises were collected with and without conscious control of the scapula. The baseline data were recorded while the subjects performed the exercises without conscious control of the scapula. The subjects performed 5 trials of each movement with 1 kg loads in their hands. Raw kinematic data were low-pass filtered at a 6-Hz cutoff frequency and converted into anatomically defined rotations. In general, we followed the ISB (International Society of Biomechanics) guidelines for constructing a shoulder joint coordinate system (Wu et al., 2005). Scapular orientation relative to the thorax was described using a Euler angle sequence of rotation about Z_s (protraction/retraction), rotation about Y'_s (downward/upward rotation), and rotation about X''_s (posterior/anterior tipping) (Ludewig and Reynolds, 2009). Full bandwidth sEMG data captured by the data acquisition software (AcqKnowledge, Biopac systems Inc., CA, USA) were reduced using a root mean square (RMS) algorithm to produce sEMG envelopes with an effective sampling rate of 50 samples. Then the data were normalized to the MVIC trials. The EMG (electromyograph) data for each muscle were averaged from the middle 3 trials. Phase was defined by a trigger marked and synchronized on the sEMG data and scapular kinematic data, based on a metronome. The mean sEMG amplitude of each muscle, reported as a percentage of MVIC, was used to assess the activity of the muscle.

1.7. Statistical analysis

SPSS 17.0 software was used for data analysis. The Shapiro–Wilk test was performed to confirm normal distribution of the data. For data with normal distribution, the three-way analysis of variance (ANOVA) with one between factor, pattern of scapular dyskinesis, and two within factors, condition (with and without conscious control) and angle, was used to determine if conscious control of the scapula could affect the kinematics and EMG muscle activities. For the arm lowering phase, angles were defined at 4 levels, 30°, 60°, 90°, and 120° arm elevation, and 5 levels, 0–30°, 30°–60°, 60°–90°, 90°–120°, and >120° arm elevation, for kinematics and EMG data, respectively. For the 2 selected exercises, angles were defined at 2 levels (60° and 90° for side-lying flexion; midpoint and maximal point for side-lying external rotation) and 2 levels (concentric and eccentric phases) for kinematics and EMG data, respectively. Bonferroni corrections were used to adjust for multiple pair-wise comparisons. For non-parametric data, the Wilcoxon signed ranks test was used to compare outcomes between conditions in subjects with specific dyskinesis patterns. Descriptive statistics were used for self-reported symptom improvement.

The choice of analysis of angles for the selected exercises was based on an analysis method from previous studies as well as the limitations of the instrumentation in the current study. Based on De Mey et al. (2013) and Cools et al. (2007), the analysis of the EMG for the selected exercises was divided into concentric, isometric, and eccentric phases. Based on Ludewig and Cook (2000), the analysis of the EMG for arm elevation was divided into different phases of motion (30°–60°, 60°–90°, 90°–120°). Thus, we analyzed the EMG data based on different phases. For the kinematics, specific angles of each phase were selected for analysis. For the side-lying flexion, the two points in mid-range (60 and 90°) of concentric and eccentric phases were selected because of the limitation of the sensor skin motion error over 120°. For the side-lying external rotation, the middle and maximal points of the concentric and eccentric phases were selected for data analysis.

As scapular dyskinesis was noted only in the lowering phase of arm elevation, we compared the kinematics and muscle activation between conscious control and no conscious control in the lowering phase.

2. Results

The patterns of scapular dyskinesis of the subjects were identified. Sixteen subjects identified as pattern I; 16, pattern II; and 28, mixed pattern I + II (Table 1). ANOVA was conducted for kinematics data, and non-parametric analysis was conducted for EMG data.

2.1. Arm elevation in the scapular plane

For scapular external rotation, the conditions responded differently across positions ($p = 0.017$). Subsequently, the effect of control was investigated for each position. Averaged across all pattern groups, external rotation was higher with control than without control (30°, 60°, 90° and 120° lowering phase) (Fig. 2A). For scapular posterior tipping, there was no control effect ($p = 0.364$). In all groups, MT was significantly higher (0°–30°; all positions except >120°; all positions except 60°–90° and >120°, respectively) with control than without control, as was LT (0°–30° and 30°–60°; all positions; all positions, respectively). In the pattern I and I + II groups, UT/LT (>120°; 60°–90° and 90°–120°, respectively) was significantly higher with control than without the control. In the pattern II group, both UT/MT and UT/LT (60°–90°, 90°–120°, and >120°) were significantly lower with control than without control.

Table 1
Participant demographic data.

Lowering phase	Pattern I		Pattern II		Pattern I + II		p-value
	Mean	SD	Mean	SD	Mean	SD	
Number	16	–	16	–	28	–	–
Gender (male/female)	11/5	–	13/3	–	20/8	–	–
Age (years)	26.6	7.2	25.9	4.9	25.4	4.2	0.77
Height (cm)	172.2	8.7	170.7	5.5	171.3	9.7	0.88
Weight (kg)	67.8	10.8	65.8	7.9	65.6	10.5	0.77
Pain (VAS*)	2.9	1.3	2.9	1.2	3.3	1.2	0.37

p-value: There were no significant differences in the basic data of the dyskinesis groups.
VAS*: visual analog scale.

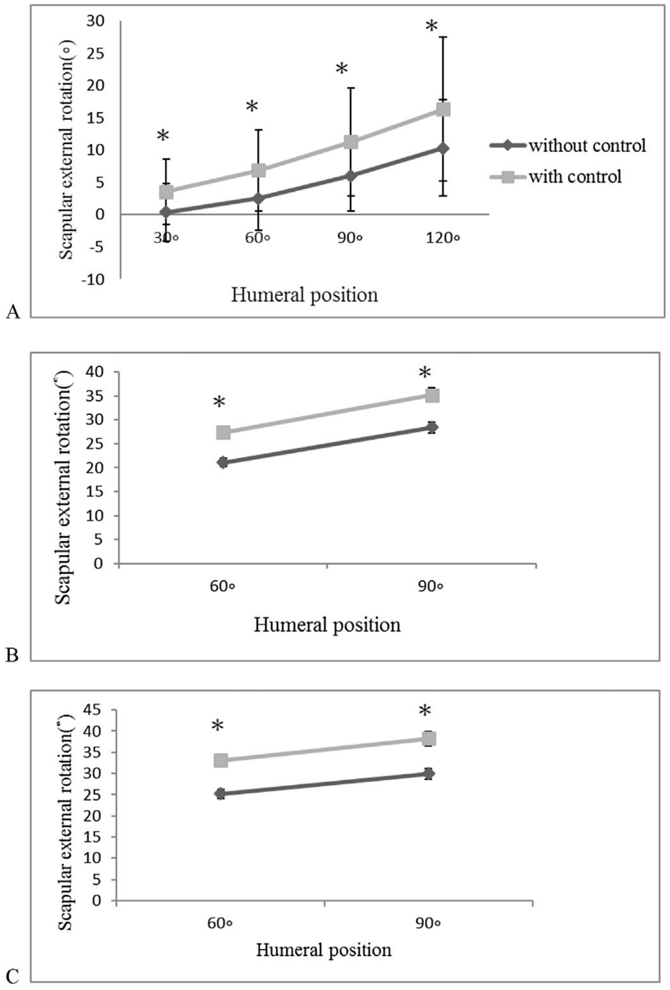

Fig. 2. Scapular external rotation with and without conscious control in (A) arm elevation in the scapular plane (B) concentric phase in side-lying elevation (C) eccentric phase in side-lying elevation.

2.2. Side-lying elevation

For scapular external rotation, the condition responded differently across positions ($p = 0.006$). Averaged across all pattern groups, external rotation in the concentric and eccentric phases was higher (60° and 90°) with control ($p < 0.001$) than without control (Figs. 2B and 4C). However, there was no significant difference between conditions for posterior tipping of the scapula ($p = 0.181$). In all 3 groups, MT and LT were significantly higher in both phases with control than without control, except for MT in the eccentric phase ($p < 0.01$) in the pattern I group. There were no differences in UT/MT and UT/LT with control (Table 2) (Fig. 3).

2.3. Side-lying external rotation

For scapular external rotation, the conditions responded differently across positions ($p < 0.001$). Averaged across all pattern groups, less external rotation was found with control than without control at the maximal and middle positions in the eccentric phase ($p < 0.001$). For scapular posterior tipping, there was no control

Table 2
Muscle activities of UT/MT, UT/LT, MT and LT during side-lying elevation.

	Pattern I				Pattern II				Pattern I + II			
	Without control		With control		Without control		With control		Without control		With control	
	con	ecc	con	ecc	con	ecc	con	ecc	con	ecc	con	ecc
UT/MT	0.45 (0.46)	0.38 (0.37)	0.44 (0.43)	0.34 (0.23)	0.44 (0.35)	0.41 (0.33)	0.44 (0.33)	0.44 (0.39)	0.54 (0.39)	0.34 (0.17)	0.47 (0.31)	0.33 (0.20)
UT/LT	0.34 (0.22)	0.28 (0.16)	0.47 (0.62)	0.38 (0.37)	0.31 (0.24)	0.34 (0.27)	0.27 (0.21)	0.29 (0.22)	0.34 (0.33)	0.29 (0.21)	0.29 (0.33)	0.25 (0.21)
MT	20.98* (25.49)	17.14 (21.60)	29.34* (28.75)	21.43 (20.17)	15.09* (8.69)	13.50* (8.71)	25.86* (21.96)	21.80* (15.86)	14.27* (9.52)	12.30* (8.67)	22.28* (14.40)	17.32* (11.14)
LT	17.34* (8.00)	13.48* (5.90)	30.36* (14.31)	18.55* (10.25)	23.85* (17.67)	18.36* (13.86)	41.64* (30.96)	31.36* (21.52)	21.33* (7.93)	14.75* (6.55)	41.57* (35.22)	23.39* (12.31)

*There was a significant increase with control ($p < 0.025$).
Pattern I: inferior angle of the scapula; Pattern II: medial border of the scapula; Pattern I + II: mixed inferior angle and medial border of the scapula.
Mean (standard deviation); con: concentric phase; ecc: eccentric phase; UT: upper trapezius; MT: middle trapezius; LT: lower trapezius.

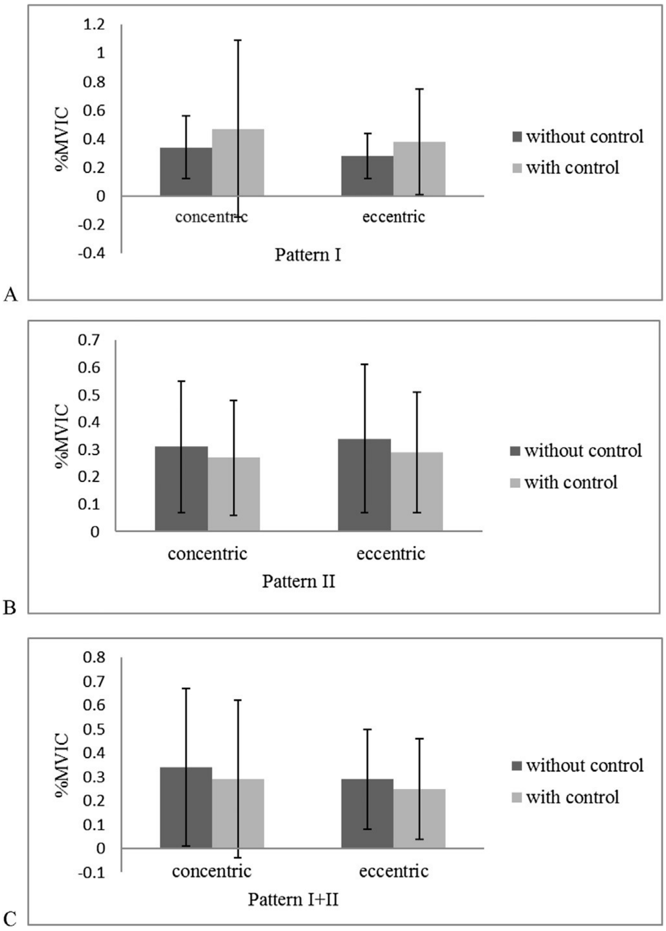

Fig. 3. Muscle balance ratio of UT/LT during concentric and eccentric phase of side-lying arm elevation in (A) pattern I (B) pattern II (C) pattern I + II.

effect ($p = 0.816$). In the pattern I group, SA and MT (concentric phase) and LT (both phases) were significantly higher with control than without control. In the pattern II group, only LT was significantly higher (in both phases) with control than without control. In the pattern I + II group, SA, MT and LT (concentric phase) was significantly higher with control than without control. In the pattern I group, UT/LT (both phases) was lower with control than without control (Table 3) (Fig. 4).

3. Discussion

Conscious control has been proposed to improve proprioception, normalize the scapular resting position, and promote trapezius muscle activation (Mottram et al., 2009; De Mey et al., 2013; Cools et al., 2014). Many studies have investigated the viability of conscious control of the scapula and its effects on scapular kinematics or related muscle activation (Mottram et al., 2009; De Mey et al., 2013). However, recent studies have included only asymptomatic subjects. The purpose of this study was to investigate whether symptomatic subjects with scapular dyskinesis can actively achieve proper scapular orientation and alter related muscle activation through conscious control.

In this study, conscious control appeared to have an impact on scapular kinematics and muscle coordination, and the changes seemed to be positive with regard to previous studies on healthy subjects. The results of this study partially confirmed our hypothesis in terms of absolute muscle activation. For the three selected exercises, conscious control of the scapula significantly increased

Table 3
Muscle activities of UT/MT, UT/LT, MT and LT during side-lying external rotation.

	Pattern I				Pattern II				Pattern I + II			
	Without control		With control		Without control		With control		Without control		With control	
	con	ecc	con	ecc	con	ecc	con	ecc	con	ecc	con	ecc
UT/MT	0.21 (0.13)	0.25 (0.16)	0.19 (0.12)	0.23 (0.16)	0.25 (0.16)	0.30 (0.20)	0.30 (0.25)	0.41 (0.36)	0.21 (0.12)	0.26 (0.13)	0.20 (0.17)	0.26 (0.19)
UT/LT	0.25$^{\#}$ (0.17)	0.33$^{\#}$ (0.22)	0.19$^{\#}$ (0.16)	0.24$^{\#}$ (0.15)	0.27 (0.19)	0.36 (0.23)	0.23 (0.18)	0.35 (0.25)	0.21 (0.23)	0.29 (0.28)	0.17 (0.15)	0.28 (0.24)
MT	25.64* (36.09)	17.94 (20.04)	35.17* (50.39)	20.71 (21.55)	23.24 (14.33)	17.43 (10.89)	26.85 (17.83)	17.97 (10.07)	22.68* (12.85)	15.01 (8.04)	30.34* (17.26)	17.46 (8.63)
LT	18.04* (13.77)	12.28* (9.28)	30.04* (17.60)	16.26* (9.10)	28.90* (41.27)	20.77* (34.68)	41.60* (47.53)	25.38* (31.49)	26.07* (14.78)	16.74 (9.13)	39.86* (26.41)	19.39 (12.80)

$^{\#}$There was a significant decrease with control ($p < 0.025$).
*There was a significant increase with control ($p < 0.025$).
Pattern I: inferior angle of the scapula; Pattern II: medial border of the scapula; Pattern I + II: mixed inferior angle and medial border of the scapula.
Mean (standard deviation); con: concentric phase; ecc: eccentric phase; UT: upper trapezius; MT: middle trapezius; LT: lower trapezius.

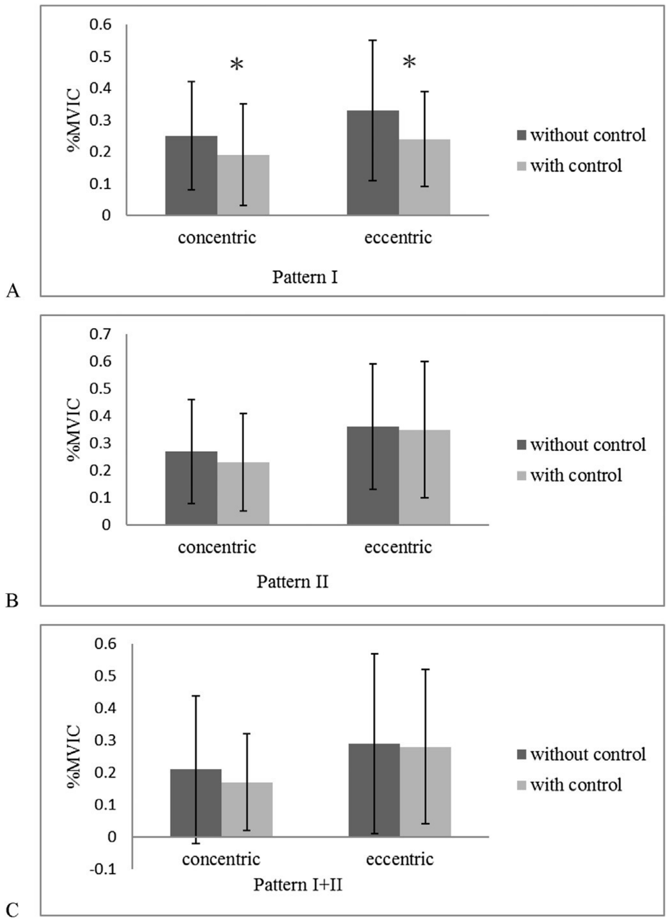

Fig. 4. Muscle balance ratio of UT/LT during concentric and eccentric phase of side-lying external rotation in (A) pattern I (B) pattern II (C) pattern I + II.

the activation of MT and LT in three pattern groups. The findings were consistent with previous studies on healthy subjects. De Mey et al. (2013) reported significantly higher activation levels in these 2 sections of the trapezius muscle in side-lying external rotation with conscious control. Mottram et al. (2009) also found significant increases in MT and LT activity when maintaining the scapula in a neutral position in a static condition with conscious control. This study demonstrated that the effects of control in symptomatic subjects are similar to those in healthy subjects.

While the 3 selected exercises may be appropriate for conscious control in terms of absolute muscle activation and ratio, arm elevation in the scapular plane should be used with caution due to the high UT/SA ratio. After investigating UT/SA ratios during selected exercises, Cools et al. (2007) reported that arm elevation was not able to produce optimal UT/SA ratios (0.8–1.0). Similarity, our results showed high UT/SA ratios (0.96–2.44). The explanation of our results could be the phase-dependent force-couple muscle activation (Magarey and Jones, 2003). Theoretically, in the first 60° of arm elevation, the primary force couple of the scapula upward rotator are the lower fibers of the SA and UT. Our results, however, showed significantly decreased activation in the SA during exercise with control in 30°–60° of arm elevation. To compensate for the lack of SA activation, excessive UT activity occurred. The high UT/SA ratios, however, might deteriorate the symptoms of the subjects (Cools et al., 2007).

The instruction “retract the scapula” promoted MT and LT muscle activations, not SA muscle activations. Mostly, the SA demonstrated significantly decreased muscle activation in the pattern I and I + II groups with control. The reason may have been the control instruction. As giving the command "retract the scapula" was an efficient way to help subjects to achieve the proper scapular position in our study, this instruction may not benefit SA activation. Scapular retraction is mainly achieved by adduction of the scapulothoracic joint, which is activated by the MT, LT, and rhomboids, as well as external rotation of the acromioclavicular (AC) joint by minor activation of the SA (Neumann, 2010). Thus, the SA is only highly active in the push phase of a push-up exercise (protraction of the SC joint) and not during the retraction movement prescribed by the control instruction in our study (Ludewig et al., 2004).

Compared with previous studies, our study had some advantages. In previous studies, the training movement was limited to arm elevation of 90° in the sagittal, frontal, or scapular planes (Roy et al., 2009). Our study used arm elevation in the scapular plane and two selected exercises with optimal muscular balance ratios suggested by previous studies (Cools et al., 2007; De Mey et al., 2013). The results of our investigation, with regard to both kinematic and muscle activity data, indicate the effects of control combined with those exercises in symptomatic subjects. Therefore, we believe that conscious control combined with those exercises can potentially change the control of the scapula.

Some limitations of our investigation should be noted. First, the main instruction used, "retract the scapula", was focused on medial rotation only. Other specific instructions for each abnormal scapular kinematic need to be further verified. Second, the symptoms of our subjects were limited to a visual analog score of less than 5, which indicates a mild degree of impairment. The effect of control in subjects with severe impairment is unknown. Third, our design lacked long-term follow-up of conscious control of the scapula. It is unknown whether the alterations indicated by our results can translate into long-term effects. Fourth, the average age of our sample was 25.8 years, limiting the generalizability of the results to patients of other age. Fifth, our design lacked a control group. It is unknown whether the alterations of scapular kinematic and muscle activation are similar or even better in healthy subjects. Furthermore, our study investigated the relevance of conscious control of the scapula in only three selected exercises. Many patients demonstrated abnormal movement patterns during daily activity, sports-related shoulder exercise, and functional movements. Whether conscious control of the scapula can alter those abnormal movement patterns is still unknown. Finally, surface electrodes were used during dynamic movements, so the influence of movement artifacts and crosstalk cannot be excluded. There may have been alterations in the signal owing to muscle movement under the electrode and crosstalk from nearby muscles.

4. Conclusions

This study demonstrated that conscious control of the scapula can alter scapular orientation and associated muscle activation in symptomatic subjects during 3 selected exercises such that it is closer to that exhibited in healthy individuals. For symptomatic subjects, side-lying external rotation is the most appropriate exercise for conscious control of the scapula, as it promotes optimal absolute muscle activations and muscle balance ratios. Although no optimal changes in muscle balance ratio were found for side-lying elevation, this exercise can increase scapular external rotation with conscious control. However, arm elevation in the scapular plane should be applied as a control exercise with caution. Validation of the long-term effects of conscious control of the scapula on muscle activation and scapular kinematics in a wide range of subjects with shoulder symptoms is needed.

Conflict of interest

None declared.

Ethical approval

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References

Alizadeh MH, Daneshmandi H, Shademan B, Ahmadizad S. The effects of exercise training on scapular position of muscle activity measured by EMG. World J Sport Sci 2009;2:48–52.

Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? Am J Sports Med 2007;35:1744–51.

Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. Br J Sports Med 2014;48:692–7.

De Mey K, Danneels LA, Cagnie B, Huyghe L, Seyns E, Cools AM. Conscious correction of scapular orientation in overhead athletes performing selected shoulder rehabilitation exercises: the effect on trapezius muscle activation measured by surface electromyography. J Orthop Sports Phys Ther 2013;43:3–10.

Huang HY, Lin JJ, Guo YL, Wang WT, Chen YJ. EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement. J Electromyogr Kinesiol 2013;23:267–74.

Huang TS, Huang HY, Wang TG, Tsai YS, Lin JJ. Comprehensive classification test of scapular dyskinesis: a reliability study. Man Ther 2015a;20:427–32.

Huang TS, Ou HL, Huang CY, Lin JJ. Specific kinematics and associated muscle activation in individuals with scapular dyskinesis. J Shoulder Elb Surg 2015b;24:1227–34.

Kendall F, McCreary E. Muscle testing and function. Baltimore, MD, USA: Williams & Wilkins; 2010.

Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. J Biomech Eng 2001;123:184–90.

Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. J Am Acad Orthop Surg 2003;11:142–51.

Kibler WB, Sciascia A. Current concepts: scapular dyskinesis. Br J Sports Med 2010;44:300–5.

Kibler WB, Sciascia A, Dome D. Evaluation of apparent and absolute supraspinatus strength in patients with shoulder injury using the scapular retraction test. Am J Sports Med 2006;34:1643–7.

Lin JJ, Hanten WP, Olson SL, Roddey TS, Soto-Quijano DA, Lim HK, et al. Functional activities characteristics of shoulder complex movements: exploration with a 3-D electromagnetic measurement system. J Rehabil Res Dev 2005;42:199–210.

Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med 2004;32:484–93.

Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276–91.

Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90–104.

Magarey ME, Jones MA. Dynamic evaluation and early management of altered motor control around the shoulder complex. Man Ther 2003;8:195–206.

Mottram SL, Woledge RC, Morrissey D. Motion analysis study of a scapular orientation exercise and subjects' ability to learn the exercise. Man Ther 2009;14:13–8.

Neumann DA. Kinesiology of the musculoskeletal system: foundations for rehabilitation. 2nd ed. St. Louis (MO): Mosby; 2010.

Perotto A, Delagi EF. Anatomical guide for the electromyographer: the limbs and trunk. Springfield, IL, USA: Charles C. Thomas; 1994.

Roy JS, Moffet H, Hébert LJ, Lirette R. Effect of motor control and strengthening exercises on shoulder function in persons with impingement syndrome: a single-subject study design. Man Ther 2009;14:180–8.

Smith J, Kotajarvi BR, Padgett DJ, Eischen JJ. Effect of scapular protraction and retraction on isometric shoulder elevation strength. Arch Phys Med Rehabil 2002;83:367–70.

Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. J Biomech 2005;38:981–92.