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Motor control retraining exercises for shoulder impingement: effects on function, muscle activation and biomechanics in young adults

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Abstract

Objective—Evidence for effective management of shoulder impingement is limited. The present study aimed to quantify the clinical, neurophysiological, and biomechanical effects of a scapular motor control retraining for young individuals with shoulder impingement signs.

Method—Sixteen adults with shoulder impingement signs (mean age 22 ± 1.6 years) underwent the intervention and 16 healthy participants (24.8 ± 3.1years) provided reference data. Shoulder function and pain were assessed using the Shoulder Pain and Disability Index (SPADI) and other questionnaires. Electromyography (EMG) and 3-dimensional motion analysis was used to record muscle activation and kinematic data during arm elevation to 90° and lowering in three planes. Patients were assessed pre and post a 10-week motor control based intervention, utilising scapular orientation retraining.

Results—Pre-intervention, patients reported pain and reduced function compared to the healthy participants (SPADI in patients 20 ± 9.2; healthy 0±0). Post-intervention the SPADI scores reduced significantly ($p<0.001$) by a mean of 10 points (±4). EMG showed delayed onset and early termination of serratus anterior and lower trapezius muscle activity pre-intervention, which improved significantly post-intervention ($p<0.05$-0.01). Pre-intervention, patients exhibited on average 4.6-7.4° less posterior tilt, which was significantly less in two arm elevation planes ($p<0.05$) than healthy participants. Post-intervention, upward rotation and posterior tilt increased significantly ($p<0.05$) during two arm movements, approaching the healthy values.

Conclusions—A 10 week motor control intervention for shoulder impingement increased function and reduced pain. Recovery mechanisms were indicated by changes in muscle recruitment and scapular kinematics. The efficacy of the intervention requires further examined in a randomised control trial.

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Keywords

shoulder impingement; rehabilitation; biomechanics; electromyography; motor control; function

1. INTRODUCTION

Shoulder disorders are the third most common musculoskeletal condition presenting in general practice, with a point prevalence of 7-26% [22]. Symptoms are often persistent and recurrent, with 40-50% of patients reporting persistent symptoms after 6 to 12 months [47] and 14% of patients continuing care after 2 years [18]. Shoulder impingement has been shown to be the most common cause of shoulder pain, constituting 74% of cases [31]. Shoulder impingement is a compression of subacromial tissues as a result of narrowing of the subacromial space [26]. The aetiology of subacromial can include anatomical and mechanical factors, rotator cuff pathology, glenohumeral instability, restrictive processes of the glenohumeral joint, imbalance of the muscles, and postural considerations [17]. Impingement syndrome can cause functional disability and reduce quality of life [25] and may contribute to the development of rotator cuff disease [26]. Several biomechanical and physiological factors have been highlighted in shoulder impingement patients [19], including altered scapular movements [19; 21] and muscle activity [20; 21].

Physiotherapy is often the first line of management for shoulder impingement [10] but systematic reviews have found little evidence to support its efficacy [8]. Since these reviews, recent evidence has demonstrated that motor control and strengthening exercises can improve function in shoulder impingement patients [34] but the evidence is limited to a small sample (n=8) single-subject study design [34]. Re-aligning the scapula can change muscle recruitment patterns in patients with neck pain [45], but this has yet to be shown in shoulder pain. Peripheral musculoskeletal impairments can be associated with cortical reorganisation [30] and movement retraining using the principles of motor learning can change motor control in athletes [37] and improve function in lower back pain patients [36].

The aim of the present study was to examine the effects of a motor control based exercise intervention for young individuals with shoulder pain and impingement signs. To assess the efficacy of this intervention, function and pain outcomes were used, together with kinematic and neurophysiological measures to examine mechanisms of recovery. It was hypothesised that motor control exercises of the scapula would retrain muscle recruitment patterns and improve scapular kinematics, reducing subacromial impingement, thus improving function and reducing pain.

2. Materials and Methods

2.1 Participants

A sample of 16 young adults with shoulder pain (mean age 24.6 ± 1.6, range 18-34 years, 11 males) and 16 healthy age and sex matched participants (22 ± 3.1 years, range 22-29 years, 11 males) were recruited from the local community. Inclusion criteria for shoulder pain were: current shoulder pain severe enough to limit activity for more than one week or requiring treatment; pain located in the subacromial region; impingement signs. Arm pain was commonly replicated with overhead arm evelation movements with combined shoulder rotation (e.g. throwing action). Mean duration of shoulder symptoms was 16 months (range 4-36 months).There was no significant difference between the healthy and shoulder pain groups for body weight (shoulder pain = 72.7kg ± 10.1, healthy = 72.3kg ± 8.8,) or height (shoulder pain = 171.6cm ± 8.9, healthy = 174.6cm ± 8.6). Written, informed consent was obtained from all participants and the study was approved by the Faculty of Health Science Ethics Committee, University of Southampton.

Exclusion criteria—all participants - past or present neck or arm pain, previous traumatic shoulder injury, neurological disease, referred pain from the cervical or thoracic spine; gleno-humeral instability; more than 3 lifetime glucocorticoid shoulder injections and/or injection in the past 3 months; current physiotherapy; contraindications for laboratory procedures (i.e. skin allergies). Those over 34 years were excluded to minimise the confounding influence of aging on rotator cuff tendinopathy.

2.2 Screening for inclusion in the study

Physical screening of participants with shoulder pain was conducted in order to define a clinical presentation of shoulder impingement using three clinical tests; Hawkins-Kennedy, Neer’s and Painful Arc (participants with 2/3 positive were included) [3]. Diagnostic ultrasound imaging was conducted by a sonographer to exclude participants with complete rotator cuff tears and biceps tendinopathy. No tears (complete or partial) were found.

2.3 Motor Control Intervention

The motor control retraining package was targeted at correcting movement impairments of the scapula by re-educating muscle recruitment. There were two components to the package:

1. Motor control exercises to correct alignment and coordination, which involve a) learning optimal scapular orientation at rest and then controlling optimal orientation during active arm movements; b) muscle specific exercises for trapezius and serratus anterior
2. Manual therapy techniques commonly used in clinical practice to manage symptoms, e.g. used to lengthen tight muscles or reduce active trigger point pain presentations.

During the motor control exercises, scapular position was optimised in relation to the thorax [28], initially by being altered manually by the therapist on a subject specific basis [28; 45]. This involved the therapist using observation and palpation to alter orientation/alignment of the scapula and clavicle using the following guidelines: Acromion should be higher than the superior medial border of scapula, the spine of the scapula should be 15-25° rotated in the coronal plane, medial border and inferior angle of scapula should be tight against the rib cage and the clavicle should have a slight posterior rotation in the frontal plane. The participant was then taught to actively reproduce this orientation using visual (in a mirror), auditory (from therapist) and kinaesthetic cues such as palpation [5]. Once the scapula was placed into an optimal position, the participant was asked to control the orientation of the scapula whilst lifting their arm to 90° humeral elevation in the frontal, sagittal, and scapular planes. Movements were performed at a slow, controlled pace and repeated for 2 minutes (i.e. 10 times). Once the participant had regained sufficient control of scapular orientation during arm movements, muscle specific motor control exercises were introduced (after 4-6 weeks). These exercises required the participant to initiate and maintain the optimal scapular orientation whilst muscle specific recruitment of serratus anterior and lower trapezius.

Retraining was performed at home twice a day for 10 weeks, with five follow up appointments with the physiotherapist during that time, to ensure the exercises were being performed appropriately. Manual therapy techniques, such as trigger point therapy and pectoralis minor supine manual stretch [2] were performed as necessary.

2.4 Data Collection

The shoulder pain group underwent two data collection sessions; immediately prior to and immediately post- the 10-week intervention (within 2 weeks). Healthy participants underwent one data collection session. The primary outcome measure of pain and function was the Shoulder Pain and Disability Index (SPADI) [32]; other questionnaires included the Disabilities of Arm Shoulder and Hand (DASH) [14], Oxford Shoulder Score [6], Short-Form 36 (SF-36) [43], and visual analogue scale (VAS) of pain [42].

Outcomes related to the mechanical aspect of the study included surface electromyography (EMG) of relevant scapulothoracic muscles and kinematic analysis of the shoulder complex during habitual active arm movements, i.e. without actively orientating the scapula prior to movement. Three slow, controlled movements in the sagittal, scapular and frontal plane of arm elevation to 90° from rest (arm by side), followed by arm lowering back to rest were performed. The dominant arm of the healthy participants and the effected shoulder of the pain group (also dominant in all cases) were analysed.

2.3.1 Scapular Kinematics and Electromyography—Retroreflective marker data were recorded using a Vicon MX T-Series motion capture system (Vicon Motion Systems, Oxford UK) consisting of 12 cameras sampling at 100Hz. An acromion marker cluster (AMC) was attached to the flat posterior portion of the acromion to measure scapular kinematics relative to the thorax (Figure 1). The AMC is known to be valid during arm elevation to 120° [39] and lowering [44]. The bony landmarks of posterior acromion (AA), root of medial spine (TS), and inferior angle (AI) were calibrated with respect to AMC before testing began using the calibrated anatomical systems technique (CAST) method [4]. An anatomical local coordinate system was then constructed from these bony landmarks following the recommendations of the International Society of Biomechanics [48].

Retro-reflective markers were also attached to the participant’s thorax (sternal notch, xiphoid process, C7 and T8 vertebra). A cuff with a cluster of markers was also fastened to the upper arm to determine the amount of humeral movement. Bony landmarks of the medial and lateral epicondyles were calibrated with respect to the arm cluster using the CAST method and the gleno-humeral joint centre was estimated from the pivot point of the instantaneous helical axis between the humerus and scapula [40]. The AMC, thoracic markers and upper arm cuff were applied by the same investigator (MW) and remained in situ during the testing protocol. Wireless surface EMG electrodes (Aurion ‘Zerowire’, Milan, Italy) were placed on upper, middle and lower trapezius, according to the SENIAM guidelines [12] and serratus anterior muscles according to Ludewig and Cook [20]. EMG data were sampled at 1000Hz and synchronised with kinematic data from the motion capture system.

2.3.2 Data reduction of kinematic and EMG outputs—Prior to further processing, all kinematic data were expressed in the thorax coordinate system. Scapular orientation with respect to the thorax was determined following a Euler angle rotation sequence of internal/external rotation (Y), upward/downward rotation (X), and anterior/posterior tilt (Z) [48]. Upward rotation angles were inverted to obtain more easily interpretable data, with an increase in value corresponding to upward rotation of the scapula. Humeral elevation with respect to the thorax was determined following a non-cardan rotation sequence of (Y) plane of elevation, (X) elevation, (Y) axial rotation [7]. Vicon BodyBuilder v3.6 (Vicon Motion Systems, Oxford, UK) software was used for processing kinematic data, which were low-pass filtered using a zero-lag 4th order Butterworth filter at 2Hz using Matlab (Version R2010b, The Mathworks Inc, Massachusetts USA) software.

Post-processing of EMG signals involved low pass filtering at 20Hz, high pass filtering at 500Hz and rectification. Onset and termination of muscle activity was determined using the

On/Off methodology by visual interpretation [13] of the filtered rectified EMG signal, and the humeral angle where this occurred was noted. Kinematic and EMG activation and termination relative to arm elevation anlge data (after onset estimation) were resampled to 101 data points to enable the kinematic data to be expressed as a percentage of activity. The mean value of three trials for all kinematic and EMG variables were used for statistical analysis.

2.5 Statistical Analysis

Descriptive statistics of the questionnaire data were presented as mean, standard deviation and range. Questionnaire data were compared pre- to post-intervention using paired t-tests. The change in score pre- to post-intervention was also compared to the minimally clinically important difference (MCID) [33]. Scapulothoracic kinematic data were compared between healthy and pre-intervention groups at rest, 90° of humeral elevation, and the end of the test (back to rest) using two factor mixed model repeated measures ANOVA with humeral elevation angle as a within-subject factor, and group as a between-subject factor. Kinematic changes from pre- to post-intervention were assessed using a two factor repeated measures ANOVA with within-subject factors of humeral angle and intervention (pre/post). The humeral angles where onset and termination of muscle activity occurred was compared pre to post intervention using paired samples t-tests in the participants with shoulder pain, and between groups using independent samples t-tests. All data was checked for normal distribution prior to analysis using the Shapiro-Wilk test.

3. RESULTS

3.1 Clinical Outcomes

Function and pain improved after 10 weeks of motor control intervention (Table 1). The Healthy control participants had full function and no pain.

The SPADI scores improved by a mean of 10 (±7.4), these changes were statistically significant ($p<0.001$; Table 1) and met the MCID of 10 points [33; 46]. Pain scores on the 10-point VAS also reduced post-intervention with a mean reduction of 3.4 points (±1.5). DASH improved by 9.2 (±10.3), whilst small improvements were also seen in the OSS (4.7±4) and SF-36 physical scores (3.8±4.9).

3.2 Musculoskeletal Outcomes

The EMG and kinematic data showed some significant differences between healthy and shoulder pain participant’s pre-intervention, with improvements post-intervention.

3.2.1 Electromyography—Timing of muscle activation was delayed significantly ($p<0.05$) in patients pre-intervention compared to healthy controls, in both serratus anterior (arm elevation in frontal 23.3° ±16.6 vs. 14.3° ±1.3 and sagittal planes 26° ±14.6 vs 19.7° ±4.5) and lower trapezius (frontal 29.8° ±17.1 vs. 18.3° ±7 and scapular planes 30.9° ±17 vs. 20.4° ±8.1). However, the most significant differences ($p<0.05$) in muscle activity patterns were seen in the early termination of activity in both muscles during arm lowering in all planes (apart from lower trapezius during frontal plane arm elevation) (Table 2). On average (across all movements) serratus anterior terminated 24.2° earlier in the arm lowering phase in the pre-intervention group compared to the healthy controls. The differences in lower trapezius termination were more modest with an average of 15° difference between groups. Upper and middle trapezius showed no significant differences between groups ($p>0.05$).

Post-intervention the delayed onset of muscle activation reduced significantly (p<0.05) for serratus anterior (Figure 2a) during frontal plane arm elevation and lower trapezius during flexion (Figure 2b) and was close to matching the arm elevation angle for the control group. There was also significantly increased (p<0.05) duration of activity to match that of the healthy group in both serratus anterior (arm lowering in all three planes) and lower trapezius (sagittal and scapular planes)with the largest gains coming in the lowering phase of the activity (Table 2).

3.2.2 Kinematics—Kinematic analysis of the scapular rotations showed significantly less posterior tilt in patients with shoulder pain pre-intervention compared to healthy control participants during arm elevation in the frontal and scapular planes (p<0.05), but not in the sagittal plane. There were no significant differences between healthy control and pre-intervention groups for upward rotation or internal rotation. There was a general trend of impingement patients having less upward rotation and posterior tilt at 90° arm elevation in all three planes pre-intervention compared to the control group (Table 3).

Post-intervention, upward rotation during arm elevation in the sagittal plane had increased significantly (p<0.05), on average by 4.8° at 90° arm elevation. The increase in upward rotation matched that of the healthy participants (Figure 3). There was also a significant increase (p<0.05) in posterior tilt during arm elevation in the frontal plane, with the greatest increases occurring at 90° arm elevation. Although general trends in increased upward rotation and posterior tilt were observed in the other glenohumeral movements, these were not found to be significant (Table 3).

4. DISCUSSION

The present study found that a 10 week motor control based intervention young adults with shoulder impingement signs improved function and reduced pain immediately post-intervention. The recovery mechanism appears to involve neurophysiological and biomechanical changes, with significant changes seen in muscle recruitment patterns previously shown to optimise scapular kinematics during humeral movements. These preliminary results provide an indication for the intervention efficacy in young adults with shoulder impingement. However, the evidence of effectiveness compared with other exercise approaches and the long-term effects over a wider age range need to be demonstrated by a randomised controlled trial (RCT).

The participants with shoulder impingement signs had pain and reduced function pre-intervention, as measured by the SPADI. These SPADI results changed significantly post-intervention reaching the MCID [33]. However, the relatively high pre-intervention function (9 subjects with SPADI < 20) may have limited the scope for improvement due to a ceiling effect. The most comparable study to the present investigation was conducted by Roy *et al* [34], which used a 4 week intervention in eight shoulder impingement patients [34]. They found improvements in SPADI for 7/8 participants and small scapular kinematic changes in most, although no EMG was recorded in that particular study to highlight changes in motor control. There were, however, several differences between Roy *et al* [34] and the present study. Firstly, their participants were older with higher pain and disability scores at baseline (age = 46 years; SPADI = 43.3 ±17.4) compared to the present study (age = 24.6 years; SPADI = 19.2 ±9.2). Secondly, the intervention was delivered differently, with Roy *et al* [34] applying two consecutive periods of different exercise programmes (the second being motor control), whereas we assessed a predominantly motor control based intervention.

The present study demonstrated how timing of muscle activation differs between shoulder pain participants and healthy participants. Delayed muscle onset has been shown during arm elevation [27; 41] and significant co-activation of middle trapezius and serratus anterior has also been shown during the arm lowering [9] in shoulder impingement patients. There are, however, to our knowledge no other reports of the early termination of muscle activity found in serratus anterior and lower trapezius during arm lowering, despite consensus on apparent altered muscle recruitment [16]. This early switching off of activity could cause loss of scapular control and potential mechanical impingement [19], previously been termed as ‘kick out’ [16]. Previous authors have stressed that exercises focusing on the dynamic control of the shoulder can significantly improve symptoms of impingement, making specific reference to serratus anterior and lower trapezius [23]. The present study has shown how a motor control intervention for shoulder impingement can alter muscle recruitment patterns in both of these key muscles. The most comparable findings were from another study by Roy *et al* [35] of the effect of one session of movement training in 33 participants, which involved motor strategies during a reaching task [35]. They found EMG and kinematic changes at the end of the training but only the EMG changes remained 24 hours later, with no further follow-up.

Although there is evidence to suggest exercise interventions can reduce shoulder impingement symptoms, there is minimal evidence of these interventions changing movement patterns of the scapula [24]. Ludewig and Braman [19] highlighted the need to link exercise regimes with changes in scapular movement patterns and motor control [19]. The present study has shown that in a small cohort of young shoulder impingement patients, motor control based exercises influenced scapular kinematics during arm movements to 90° elevation. The significance of the changes in kinematics between pre- and post-intervention were limited, with the only statistically significant changes seen in upward rotation of the scapula during sagittal plane arm elevation and scapular posterior tilt during frontal plane arm elevation. Other studies have also shown the difficulty in achieving a significant change in scapular kinematics [24; 38]. The wide variation in data and the small study limited the present studies ability to identify statistical differences in kinematics. Lack of statistical significance could have also been influenced by errors in the motion analysis protocol. Previous research has shown visual observation of scapular dyskinesis had a high repeatability and sensitivity, which would be more clinically applicable [38].

4.1 Limitations of the study

Whilst the number of participants (n=16) was greater than n=8 in the previous study of motor control retraining [34], the convenience sample used in the present study was underpowered. Other limitations of this and the previous study [34] were that they lacked a control intervention, blinding and follow up testing to assess the long-term effects. This study was not representative of the majority of patients typically presenting to general practitioners, predominantly aged 50-75 years [1], who have more chronic conditions. Clinical assessment of impingement signs provides an indication of impingement but do not indicate the mechanism of impingement. The use of repeat assessment before and after an injection of lidocaine solution may have increased the accuracy of diagnosis [29]. Limitations in both the outcome measures for the mechanistic aspect of the study are well recognised. The acromion marker cluster method in the measurement of scapular kinematics is prone to error due to skin movement artefact [15], and surface EMG is prone to cross-talk of muscle activity and poor reliability of magnitude measures (based on amplitude) between sessions. Although evidence has been provided for the efficacy of the motor control concept, exercises were limited to 90° arm elevation, which is not in the functional range for some activities. This study also only focused on the painful shoulder of impingement participants and the dominant shoulder of the healthy controls. Analysis of the contralateral shoulder would have added to the scope of these findings, with the potential to examine bilateral asymmetries as a result of a more global change in the neural control of the muscles around the shoulder. However, previous studies have shown unilateral shoulder impingement can have bilateral effects on scapular kinematics [11].

5. CONCLUSIONS

The present findings suggest a 10 week motor control exercise intervention can improve function and pain in young adults with shoulder impingement signs. The findings also indicate that the recovery mechanism involves improvements in muscle recruitment patterns and scapular kinematics. Evidence of clinical effectiveness in the long-term compared with other exercise interventions needs to be confirmed by an RCT involving a wider age range of shoulder impingement patients and other intervention approaches.

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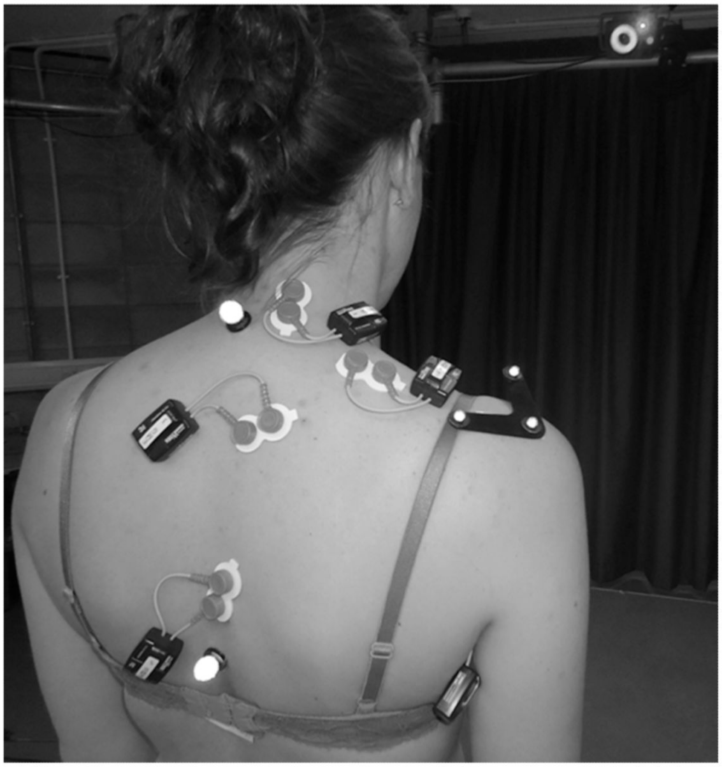

Figure 1.
Acromion marker cluster location (AMC) and electromyography electrode placements.

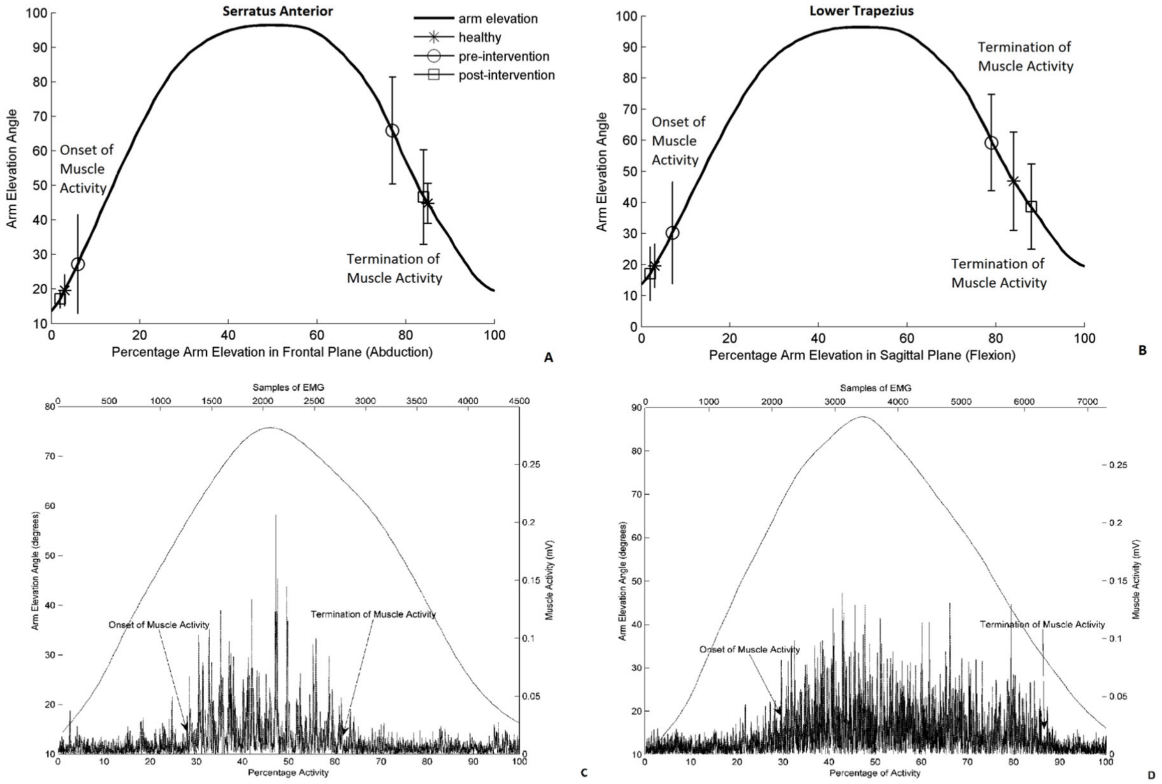

Figure 2.

Muscle activation timing in relation to arm position: (a) serratus anterior muscle activation onset during the elevation phase and termination during the lowering phase in the frontal plane. (b) lower trapezius onset and termination during arm movement in the sagittal plane. Mean and standard deviation (error bar) arm position of muscle onset and termination of muscle activity. Graph to show electromyography muscle activation relative to arm elevation angle in one participant prior to (c) and post- (d) the ten week intervention

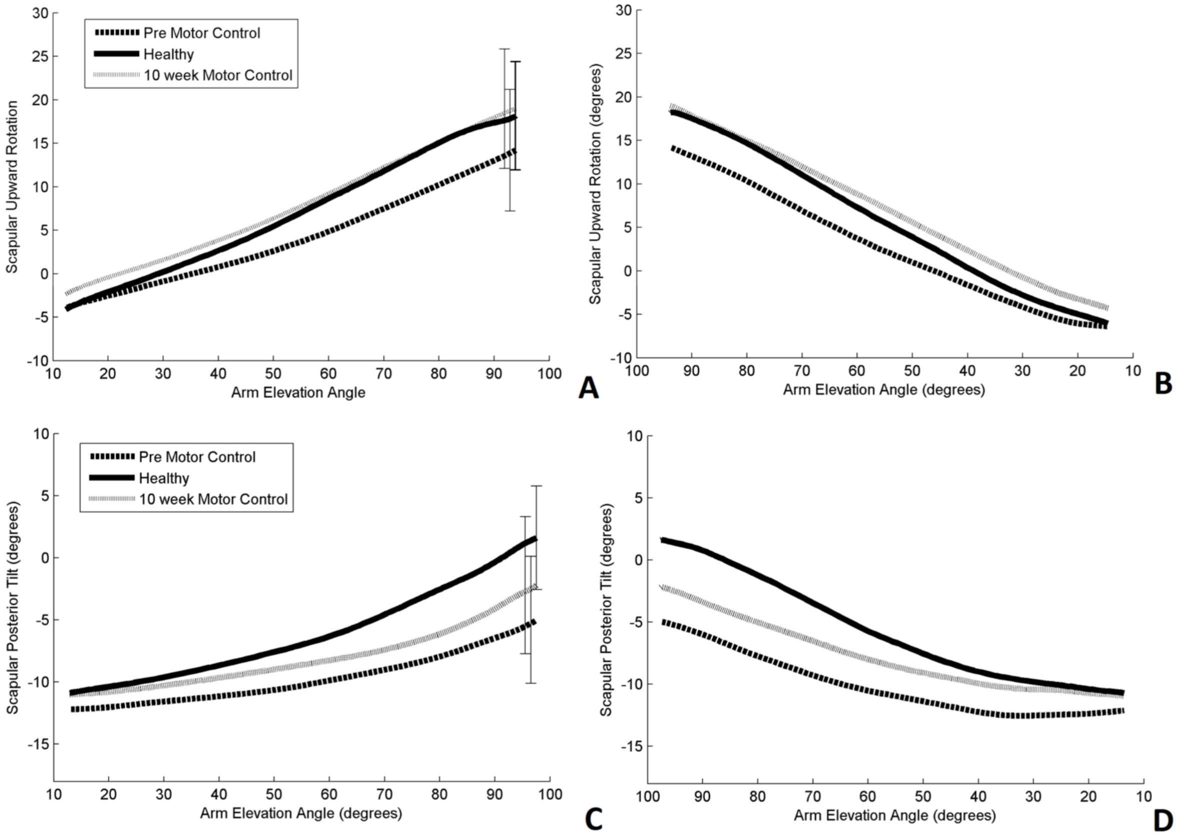

Figure 3.

Scapular kinematics: (a) mean upward rotation from rest to 90° arm elevation (b) mean upward rotation from 90° arm elevation to rest (c) posterior tilt during sagittal plane arm movement from rest to 90° (d) posterior tilt during sagittal plane arm movement from 90° to rest.

Table I

Clinical outcomes: Shoulder Pain and Disability Index (SPADI, 0-100),Disabilities of Arm Shoulder and Hand (DASH, 0-100), Oxford Shoulder Score (OSS, 0-48), Short-Form 36 (SF-36, 0-100), visual analogue scale (VAS, 1-10) pain.

Group	SPADI	SPADI (pain)	DASH	OSS	SF-36 (phys)	Pain (VAS)
Healthy (n=16)	0 ±0 0-0	0 ±0 0-0	0 ±0.4 0-1.4	48 ±0 48-48	53.3 ±2.6 53-62	0 ±0 0-0
Pre-intervention (n=16)	19.9 ±9.2 5.4-34.5	37.3 ±15.9 12-68	17.0 ±11.4 5-49.2	39.4 ±4.8 27-47	48.8 ±5.7 36-58	4.9 ±1.6 3-8
Post-intervention (n=16)	10.1 ±7.8 2.5-29	19.4 ±14.2 4-52	7.8 ±6.4 1.6-24.9	44.1 ±2.9 36-48	52.6 ±4.7 43-58	1.5 ±1.2 0-5

Mean ± standard deviation and range.

Table II

Muscle activation timing for serratus anterior and lower trapezius during arm elevation and lowering in the sagittal, scapular and frontal planes. Arm position (degrees) where muscle onset during the elevation phase, and termination of muscle activity during the lowering phase, are presented for the healthy control and shoulder impingement group pre- (Pre-M-C) and post (Post-M-C intervention

Phase	**Group**	**Arm elevation (degrees)**		
		Sagittal plane	**Scapular plane**	**Frontal plane**
Serratus Anterior				
Elevation (muscle On)	Healthy	14.3 ±1.3	16.5 ± 3.4	19.7 ± 4.5
	Pre-MC	23.3 ±16.6[#]	22.4 ± 14.1	26 ±14.6 [#]
	Post-MC	21.4 ± 13.6	20.7 ± 13.3	15.6 ± 2.7
Lowering (muscle Off)	Healthy	45.1 ± 12.9	40.1 ± 11.2	44.1 ± 5.8
	Pre-MC	60.3 ± 17.9[##]	68.8 ± 13.6[###]	66.7 ± 15.5[###]
	Post-MC	45.6 ± 10.8 [***]	53 ± 17.1 [**]	46.9 ± 14.3 [***]
Lower Trapezius				
Elevation (muscle On)	Healthy	18.3 ± 7	20.4 ± 8.1	29.5 ±10.9
	Pre-MC	29.8 ± 17.1 [##]	30.9 ± 17 [#]	35.5 ± 18.9
	Post-MC	17 ± 4.3 [*]	22.8 ± 13.3	30.5 ± 20
Lowering (muscle Off)	Healthy	46 ± 16.1	38.7 ± 12.4	56.9 ± 20
	Pre-MC	58.8 ± 16.3 [#]	61.2 ± 14.2[###]	66.5 ± 16.2
	Post-MC	42 ± 13.7 [**]	50.7 ± 20 [*]	59.3 ± 23

Mean ± standard deviation.

[*] Significant difference pre- to post intervention.

[#] Significant difference between healthy control and participants with pain.

Significance level indicated by; [*/#] p<0.05,

[**/##] p<0.001

[***/###] p<0.0001.

MC, motor control

Table III

Scapular orientation (upward rotation and posterior tilt) at the start (0°), 90° arm elevation, and end point (0°) after lowering the arm during each plane of arm movement for the healthy group and shoulder impingement group pre- (Pre-M-C) and post (Post-M-C) motor control intervention.

		Upward Rotation (deg.)			Posterior Tilt (deg.)		
Plane of arm movement	**Arm pos.**	**Healthy**	**Pre-M-C**	**Post M-C**	**Healthy**	**Pre-M-C**	**Post M-C**
Sagittal plane	Start	−2.7 ± 3.6	−4 ± 7.1	−2.3 ± 5.5	−11.3 ± 4.1	−12.3 ± 3.7	−11.3 ± 3.8
	90	18.3 ± 5.9	14.2 ± 7	19 ± 6.9	−0.7 ± 6.5	−5.3 ± 6.9	−2.5 ± 5.9
	Rest	−5.3 ± 3.4	−6.4 ± 7.6	−2.8 ± 8.7	−10.7 ± 4.4	−11.7 ± 3.9	−11.1 ± 4
Scapular plane	Start	−4 ± 5.4	−5.4 ± 6.5	−4.8 ± 5.4	−10.7 ± 4.3	−12.2 ± 3.7	−11 ± 3.7
	90	17.4 ± 5.5	14.1 ± 5.9	16.7 ± 5.1	2.4 ± 7.9	−5 ± 5.1	−2.2 ± 5.5
	End	−6 ± 4.9	−6.8 ± 7	−3.1 ± 8	−10.9 ± 3.7	−12.1 ± 3.7	−10.9 ± 3.8
Frontal plane	Start	−5.1 ± 3.3	−5.5 ± 6.5	−4.2 ± 6.6	−10.8 ± 3.6	−12 ± 3.4	−10.4 ± 3.5
	90	17.9 ± 6.1	15.5 ± 7.1	15.3 ± 6.5	3.6 ± 8.2	−3.3 ± 5.9	0.4 ± 5.1
	End	−4.5 ± 3.9	−4.7 ± 6.7	−1.1 ± 8.4	−10.6 ± 3.6	−12.5 ± 3.5	−10.2 ± 4.4

Mean ± standard deviation.