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Study of the scapular muscle latency and deactivation time in people with and without shoulder impingement

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ABSTRACT

Changes in muscle activities are commonly associated with shoulder impingement and theoretically caused by changes in motor program strategies. The purpose of this study was to assess for differences in latencies and deactivation times of scapular muscles between subjects with and without shoulder impingement. Twenty-five healthy subjects and 24 subjects with impingement symptoms were recruited. Glenohumeral kinematic data and myoelectric activities using surface electrodes from upper trapezius (UT), lower trapezius (LT), serratus anterior (SA) and anterior fibers of deltoid were collected as subjects raised and lowered their arm in response to a visual cue. Data were collected during unloaded, loaded and after repetitive arm raising motion conditions. The variables were analyzed using 2 or 3 way mixed model ANOVAs. Subjects with impingement demonstrated significantly earlier contraction of UT while raising in the unloaded condition and an earlier deactivation of SA across all conditions during lowering of the arm. All subjects exhibited an earlier activation and delayed deactivation of LT and SA in conditions with a weight held in hand. The subjects with impingement showed some significant differences to indicate possible differences in motor control strategies. Rehabilitation measures should consider appropriate training measures to improve movement patterns and muscle control.

1. Introduction

Shoulder impingement is a common clinical diagnosis for patients with shoulder pain and dysfunction (van der Windt et al., 1995). The diagnosis has been associated with changes in shoulder kinematics including a decrease in scapular posterior tilt, decrease (Endo et al., 2001; Ludewig and Cook, 2000; Lukaseiwicz et al., 1999) or increase in scapular upward rotation (McClure et al., 2006) and increase in scapular internal rotation (Ludewig and Cook, 2000; Warner et al., 1992). Changes in muscle activity including increased upper trapezius activity (Lin et al., 2005; Ludewig and Cook, 2000; Peat and Grahame, 1977) and decreased serratus anterior activity (Lin et al., 2006; Peat and Grahame, 1977; Scovazzo et al., 1991) have also been reported in people with shoulder dysfunctions.

The mechanisms suggested for the muscle activity changes in people with impingement include muscle strength changes secondary to pain or fatigue, structural deficits due to tendon tears; and altered motor control strategies. Scapular muscle activity found during the most studied motion of arm elevation does not exceed 25–30% of maximum voluntary contraction under unloaded conditions (Lin et al., 2005; Ludewig and Cook, 2000). These values are small enough as to not likely be affected by strength differences across groups. However, differences in muscle activities (Phadke et al., 2009) may suggest a change in motor control strategy in patients which contributes to altered kinematics while using their arm overhead. Studies have shown changes in kinematics (Scibek et al., 2009) and improvement of strength (Ben-Yishay et al., 1994) in subjects with full thickness rotator cuff tears after pain relief obtained by subacromial injections. These results suggest that pain may be a greater contributory mechanism for the changes in muscle activity than structural deficits. Pain has been associated with inhibition of muscles and changes in motor programs such that patients use altered movement patterns (Hodges and Moseley, 2003). Fatigue associated with repetitive motion could also affect muscle strength and movement patterns. Repetitive motion tends to aggravate the problems associated with extrinsic compression (Soslowsky et al., 2002). It is also postulated that repetitive motion and loading the arm makes a lack of scapular muscle control more visibly apparent (Warner et al., 1992).

One of the few ways in which muscle/motor control is studied is through study of muscle activation and deactivation time. Contraction of other muscles before the prime mover, that is, anticipatory or feedforward activation, suggests the presence of motor control programs. Furthermore, changes in the feedforward contractions or earlier/desynchronized deactivation could suggest alterations

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in these motor programs. Though previous investigations made contributions to the issue of muscle recruitment in people with impingement, they are constrained by inadequate power and lack of comparative analysis of scapular and glenohumeral muscle latencies (Moraes et al., 2008; Santos et al., 2007; Wadsworth and Bullock-Saxton, 1997). Wadsworth and Bullock-Saxton (1997) studied scapular muscle latency in swimmers and revealed that muscle latency of serratus anterior was delayed bilaterally in patients; and there was increased variability associated with muscle latencies in subjects with shoulder pain, demonstrated by larger within and between subject variance. Past studies (Moraes et al., 2008; Wadsworth and Bullock-Saxton, 1997) found that the recruitment order for scapular muscles is upper trapezius activation followed by serratus anterior and lower trapezius activation.

To our knowledge, effects of loading and repetitive motion have not yet been studied on motor latency of scapular muscles, especially in people with impingement. The primary purpose of the proposed study was to identify differences, if any existed, between activation and deactivation of trapezius and serratus anterior in patients with impingement syndrome as compared to asymptomatic controls. The hypotheses were that (1) order of recruitment would be serratus anterior activation followed by upper and lower trapezius in healthy subjects; (2) across conditions, there would be a significant delay in relative latency of serratus anterior and lower trapezius and significantly shorter relative latency of upper trapezius in people with impingement as compared to healthy subjects; and (3) the angular value of humeral elevation when each scapular muscle would be deactivated would be significantly lower in healthy subjects as compared to people with impingement.

2. Materials and methods

The study was approved by The Human Subjects Institutional Review Board at the (University of Minnesota). A convenience sample of 25 subjects with impingement were screened and initially included. This was followed by inclusion of 24 healthy individuals matching the impingement group for age, gender and hand dominance (Table 1). Each subject read and signed a consent form prior to participation.

Subjects were included if they were between 18 and 60 years of age. They were included if they had a body mass index (BMI) < 28, as extra subcutaneous tissue can compromise the quality of myoelectric signals and cause larger skin slip errors for kinematic data. Symptomatic subjects were included if they had full range of motion at the shoulder, history of non-traumatic onset of shoulder pain which had lasted for more than 6 weeks, at least two positive impingement tests (Neers, Hawkins, posterior impingement), pain during active or resisted motion in elevation/external rotation, and visible scapular dyskinesia during active motion. Information regarding past clinical information on shoulder pathology as well as the DASH (Disabilities of the Arm, Shoulder and Hand) functional status measure and Penn shoulder scores were collected.

Healthy subjects were included if they had full pain-free range of motion at the shoulder, no past history or current shoulder joint pain or tenderness and no visible scapular dyskinesia while raising or lowering their arm without an additional weight held in the hand. Subjects were excluded if they had any history of trauma, fractures, dislocations, diagnosed full thickness rotator cuff tears, adhesive capsulitis, radicular symptoms, neurological disorders, spinal deformities or known tape allergies.

Kinematic data were measured using the Flock of Birds minibird hardware (Ascension Technology, Burlington, VT) and MotionMonitor software (Innovative Sports Training, Chicago, IL) at a sampling rate of 100 Hz. The system has a reported accuracy within a range of 1.2 m from the transmitter to be 1.8 mm root mean square (RMS) for static position and 0.5° RMS for static orientation of the sensor (Innsport Sports Training, Chicago, IL). The electromagnetic sensors were placed over the sternum, distal acromion and on a thermoplastic cuff worn over the distal arm for tracking trunk, scapular and humeral motion respectively (Fig. 1a and b). Anatomical landmarks were digitized using a stylus with known

Table 1
Descriptive statistics for the demographic variables and functional rating scores.

	Healthy (n = 25)	Impingement (n = 24)	p Value
Age	32.20 (9.8)	35.09 (12.5)	0.38
Gender	13 Females, 12 males	10 Females, 14 males	0.47
Height (cm)	171.50 (8.5)	173.77 (10.3)	0.41
Weight (kg)	67.85 (9.9)	70.85 (11.2)	0.33
BMI	23.16 (2.6)	23.34 (2)	0.78
Hand dominance	23 Right sided	23 Right sided	0.58
Tested side	8 Left, 17 right	7 Left, 17 right	0.83
DASH scores	1.67 (3.1)	16.84 (9.6)	<0.001
Penn shoulder score	49.1 (6.5)	59.1 (1.8)	<0.001

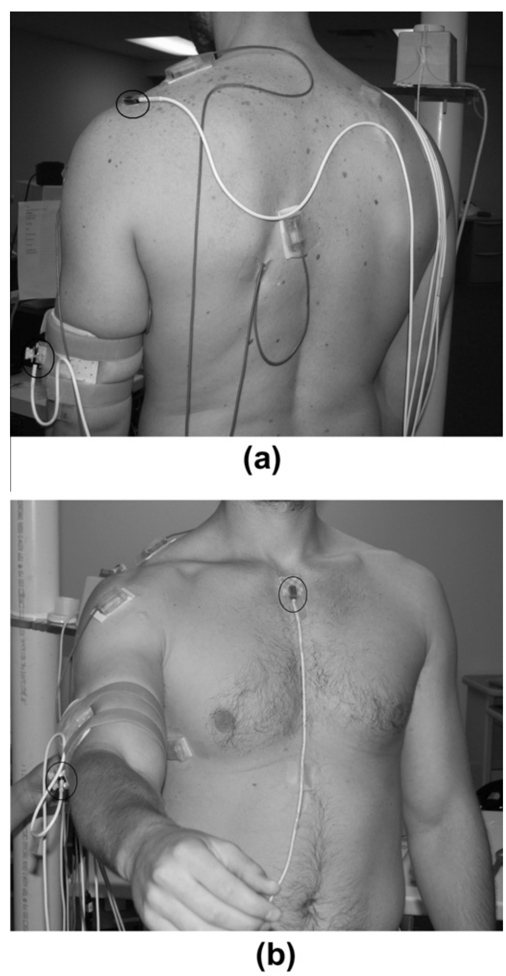

Fig. 1. (a and b): Kinematic (circled) and EMG electrode set up. Electrode placements: Upper Trapezius – 2 cm lateral to the midpoint on a line joining the C7 spinous process and tip of the acromion process. Lower Trapezius – midway between the inferior angle of the scapula and the T7 spinous process at 125° scapular plane elevation. Serratus anterior – over the 7th intercostal space, just anterior to the fibers of latissimus dorsi, at 125° scapular plane elevation. Anterior deltoid – 2 finger breadths below the acromion process.

tip offsets to build local coordinate systems for each segment using the ISB recommendations (Wu et al., 2005).

Myoelectric data were captured using the EMG system (Therapeutics Unlimited, Iowa City, IA, USA) from the upper and lower fibers of trapezius, serratus anterior, and anterior deltoid for each subject (Fig. 1a and b). Silver/silver chloride bipolar active circular electrodes of diameter 8 mm and inter-electrode distance of 2 cm were used for collecting signals with an onsite gain of 35. Signals were further amplified using an adjustable gain setting, input impedance of >15 MΩ at 100 Hz, CMRR of 87 dB at 60 Hz, and noise < 2.0 μv RMS referred to input. Signals from the electrodes were amplifier filtered using a 20 Hz high pass filter to reduce cable artifact. This raw EMG was sampled at 2500 Hz using a 16 channel A/D board and MotionMonitor software. Raw signals were monitored on an oscilloscope (Tektronix Inc., OR, USA) throughout data collection. To remove noise signals collected due to electromagnetic pulses of the Flock of Birds, the EMG raw signals were filtered using 8 notch filters after calibrating for specific frequencies using MotionMonitor software (Innovative Sports Training).

Data were collected using a protocol (Fig. 2). Subjects received a verbal command followed by a light signal. They were instructed to move as soon as they saw the light. EMG signal before the light trigger was used as baseline data for latency calculations. Subjects were not constrained to assume any forced rotations of the arm and were instructed to move naturally. The loaded and unloaded trials were randomized using a coin flip. In the case of loaded trials, the subject was given a weight in hand between 2 and 4 kg (normalized according to their BMI and arm length). Subjects were asked to rate their pain using a 0–10 numerical pain rating (NPR) scale, and exertion on the Borg's scale of perceived exertion (RPE) after each trial.

Kinematic data were reported using ISB recommended Euler angle sequences. MATLAB was used to full wave rectify and further smooth the EMG data using a 50 Hz low pass 7th order Butterworth filter. For calculation of muscle latency, baseline EMG was calculated as the average of the 50 ms before the light trigger. Muscle activation was identified as the point during EMG activity where the mean of a moving window of 25 ms exceeded the baseline activity by three standard deviations (Hodges and Bui, 1996). Each onset time was checked visually to identify EMG trials disrupted by cardiac or other motion artifacts. Relative latency of scapular muscles was calculated as a difference of their latency relative to that of the anterior deltoid. The onset of a muscle was termed as feed-forward if it had an onset before or up to 50 ms after the onset of anterior deltoid which is the prime mover (Hodges and Richardson, 1996). The deactivation time was identified when the mean of the moving window was lower than or equal to the sum of mean baseline activity plus three standard deviations. The corresponding humerothoracic elevation angle was recorded for further analysis. In cases when the muscle never fully deactivated, the lowest humeral elevation angle was considered as the angle for analysis. The muscle was only considered activated or deactivated if the activity remained higher or lower respectively than the threshold level in the subsequent windows of the identified time-point.

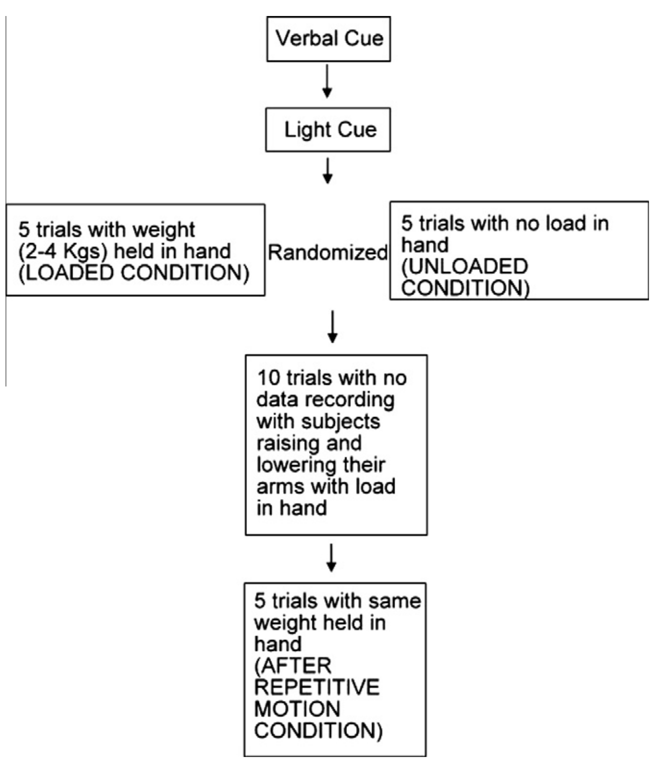

Fig. 2. Protocol for data collection.

2.1. Data analysis

The study primarily intended to determine if group differences existed for latency across different conditions. The dependent variables were muscle relative latencies of upper and lower trapezius and serratus anterior and the humeral angle corresponding to muscle deactivation. The independent variables were groups (with and without impingement) and conditions (unloaded, loaded and after repetitive motion). Level of significance was 0.05 for all tests. For all variables, the within subject trial to trial reliability of the five trials was tested by calculating the ICCs (intraclass correlation coefficients; Model 3 and type (3,1)) and SEMs (standard errors of measurement). Preliminary testing determined the absence of any trial effects. In subsequent analyses, the average of all trails was used for each subject and condition.

For testing the first hypothesis, a 3 way (group × condition × muscle) mixed model ANOVA was used. Transformations were attempted to normalize the data in conditions when the assumptions for parametric analyses were not met. In cases when transformations failed, data from individual subjects that were outliers were excluded. In the case of significant 3 way interactions further analysis was done at each level of the main factor of interest by multiple 2 way ANOVAs. The other hypotheses were tested using 2 way (group × condition) mixed model ANOVA. In the case of significant 2 way interactions, follow up comparisons were made using Tukey–Kramer adjusted post hoc analyses. Age, BMI, pain level measures using a NPR scale, Borg's scale index, DASH scores and the speed of motion calculated as average humeral velocity for elevation and lowering phases were considered as possible covariates. In case of significant correlation of these variables with the dependant variables, an ANCOVA was performed.

3. Results

The ICCs were low and the SEMs for relative latency ranged from 73 to 135 ms (Table 2). None of the considered covariates were retained for the analyses. Data from six subjects, that were consistently present across all conditions beyond the threshold of 1.5 times the inter-quartile distance, were not included in the analysis as their inclusion, despite transformations, resulted in the data being inappropriate for parametric statistics.

3.1. Hypothesis 1

The results from the 3 way ANOVA testing order of muscle recruitment showed a significant interaction between muscle

Table 2
Intraclass correlation coefficient (ICC) and standard error of measurement (SEM) for relative latency of scapular muscles.

Variable	Condition	Group	ICC	SEM (in ms)
Upper trapezius (relative latency)	Unloaded	Healthy	0.13	101.0
	Loaded	Healthy	0.30	121.6
	ARM	Healthy	0.29	112.5
	Unloaded	Impingement	NS	78.9
	Loaded	Impingement	0.16	102.7
	ARM	Impingement	0.13	79.7
Lower trapezius (relative latency)	Unloaded	Healthy	0.20	135.2
	Loaded	Healthy	0.17	103.0
	ARM	Healthy	0.43	95.3
	Unloaded	Impingement	NS	98.0
	Loaded	Impingement	0.20	92.1
	ARM	Impingement	0.29	105.3
Serratus anterior (relative latency)	Unloaded	Healthy	NS	80.3
	Loaded	Healthy	NS	110.7
	ARM	Healthy	NS	73.4
	Unloaded	Impingement	0.17	117.0
	Loaded	Impingement	NS	122.4
	ARM	Impingement	0.12	111.2

NS = non significant *F*-ratio for the between subject factor in the one way ANOVA and ARM = after repetitive motion condition.

recruitment and condition (df = 4/164; *F*-ratio = 14.57; $p < 0.001$) (Fig. 3). The serratus anterior (18.2 ms after deltoid) and upper trapezius (17.7 ms after deltoid) were recruited significantly before lower trapezius (64.6 ms after deltoid) for the unloaded condition. There was no significant difference between upper trapezius and serratus anterior relative latency for the unloaded condition. In the loaded condition, the serratus anterior (2.4 ms after deltoid) and lower trapezius (8.8 ms after deltoid) were recruited significantly before the upper trapezius (60.3 ms after deltoid) ($p < 0.05$). This order of recruitment continued in the condition after repetitive motions with the serratus anterior (3.7 ms before deltoid) and lower trapezius (22.2 ms after deltoid) getting recruited significantly before upper trapezius (54.8 ms after deltoid) ($p < 0.05$). There were no significant differences between lower trapezius and serratus anterior relative latency in loaded and after repetitive motion conditions.

3.2. Hypothesis 2

The relative latency of upper trapezius significantly increased from the unloaded (19.2 ms before deltoid) to the loaded condition (71.7 ms after deltoid) in both groups (Fig. 4a). The relative latency of lower trapezius significantly reduced from the unloaded (65.1 ms after deltoid) to the loaded condition (6.8 ms after deltoid) ($p < 0.05$) in both groups (Fig. 4b). The serratus anterior showed a strong trend ($p = 0.052$) of decreasing relative latency from the unloaded condition (18.7 ms after deltoid) to the loaded condition (5.6 ms after deltoid) in both groups (Fig. 4c). The upper trapezius data was also analyzed for each condition separately. This was done because the upper trapezius showed a high baseline activity in both the conditions with weight held in the hand and hence the activation as detected by the algorithm (compared to a higher baseline) was delayed. The 2 sample *t*-test for upper trapezius relative latency during the unloaded condition showed a group difference (*t*-value = 2.95; $p = 0.005$) for the subjects with impingement (4.24 ms before deltoid) recruiting their upper trapezius significantly earlier than healthy controls (42.7 ms after deltoid).

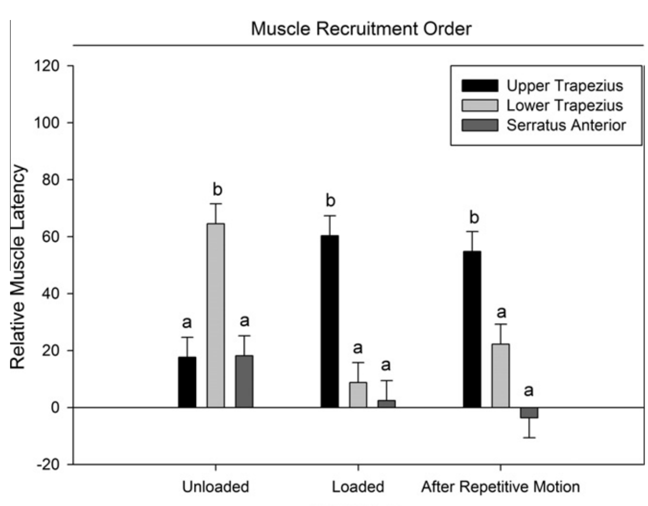

Fig. 3. Relative latency of scapular muscles for each condition averaged across groups. Different letters ('a', 'b') are assigned to signify differences between muscles ($p < 0.05$) during individual conditions. Hence, assignment of the same letter signifies no difference between the muscle latency.

3.3. Hypothesis 3

The humerothoracic elevation angle where serratus anterior was deactivated was significantly higher (~9°) in the subjects with impingement (36.4°) as compared to healthy controls (27.7°) across all conditions (df = 1/47, *F*-ratio = 6.69; $p = 0.013$). (Fig. 5c) There was also a significant main effect of condition such that the serratus anterior was deactivated much later in the range of arm lowering in the loaded condition (27.6°) and the condition after repetitive motions (29°) as compared to the unloaded condition (39.6°) (df = 2/94; *F*-ratio = 26.0; $p < 0.001$) in both groups. There were no group differences for humerothoracic elevation angle associated with muscle deactivation of upper and lower trapezius (Fig. 5a and b). However, there was a significant condition main effect with both muscles showing significantly lower humerothoracic elevation angles before deactivation during the loaded condition (~20°) and after repetitive motions (~15°) as compared to unloaded trials ($p < 0.05$) (Fig. 5a and b).

4. Discussion

This study found an earlier activation of upper trapezius in the unloaded condition and earlier deactivation of serratus anterior across all conditions in subjects with impingement as compared to healthy individuals. This earlier latency of upper trapezius is concordant with results of earlier studies which demonstrated higher amplitude of upper trapezius activity in people with impingement (Ludewig and Cook, 2000; Peat and Grahame, 1977). It is possible that people with impingement use a different motor strategy and depend on their upper trapezius to elevate

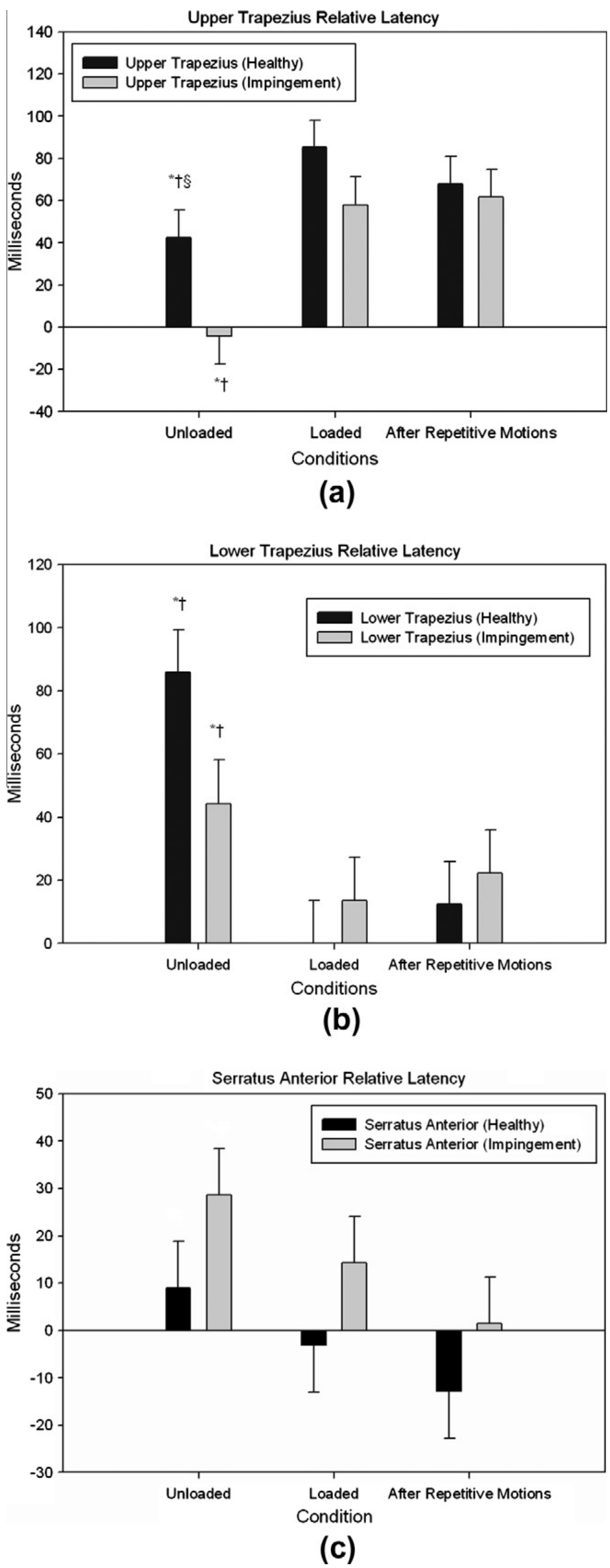

Fig. 4. (a–c): Relative latency of scapular muscles. * signifies difference between the unloaded condition and loaded condition ($p < 0.05$). † signifies difference between the unloaded condition and the after repetitive motion condition ($p < 0.05$).

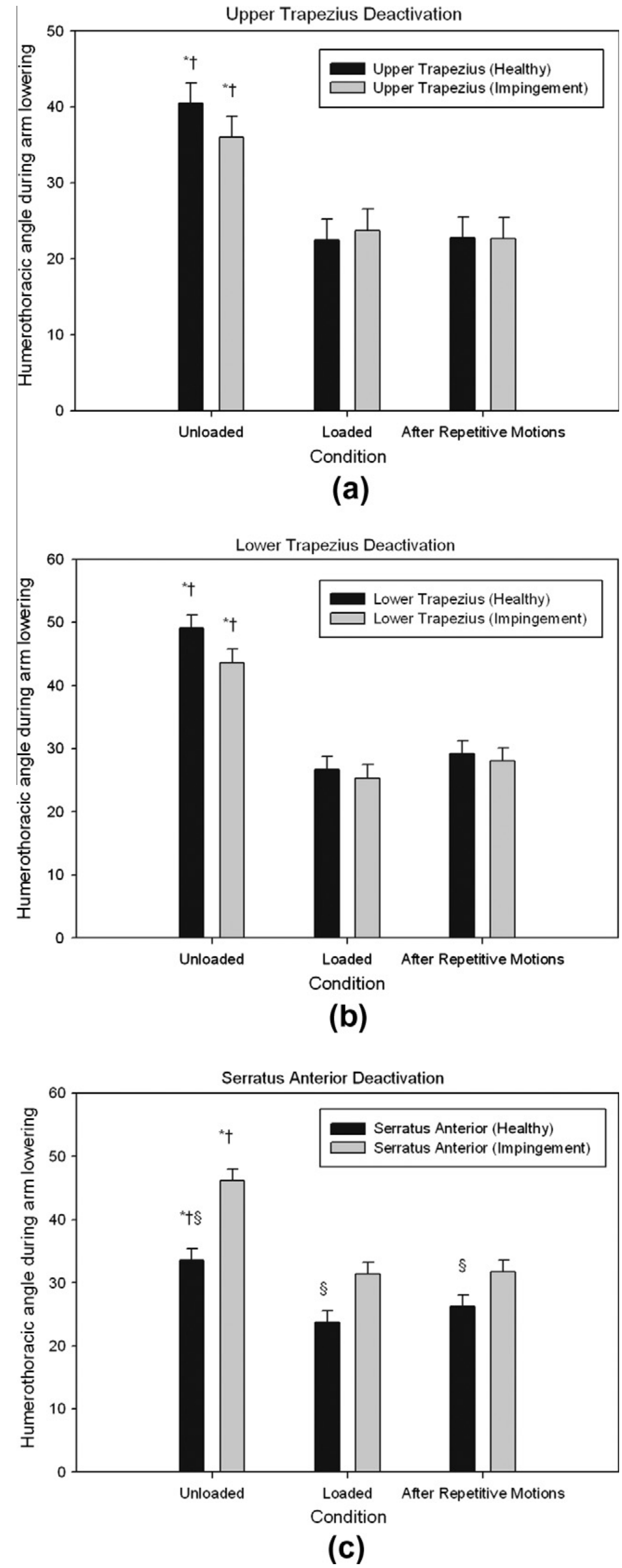

Fig. 5. (a–c) Humerothoracic angle corresponding to deactivation of scapular muscles. * signifies difference between the unloaded condition and loaded condition ($p < 0.05$). † signifies difference between the unloaded condition and the after repetitive motion condition ($p < 0.05$). § signifies group difference at a condition ($p < 0.05$).

their clavicle in an attempt to elevate their arm (Phadke et al., 2009). The upper trapezius showed a higher baseline activity when a weight was held in hand, thus increasing the threshold to determine activation. This may have happened to stabilize the shoulder girdle against the downward pull of the weight. The lower trapezius activated earlier during the loaded conditions. This possibly could be due to the enhanced demand for scapular upward rotation or the lower fibers might be co-activated with the already active upper trapezius. The motion of raising and lowering the arm is accomplished by coordinated and organized muscle activity maintaining relative balance between muscle groups. Over reliance on one group or muscle over others affects this intricate balance and suggests alteration instead of a complete failure of a motor program.

The earlier deactivation of serratus anterior is in agreement with the clinical finding of earlier studies (Warner et al., 1992) that dyskinesia was present in subjects with impingement in the lowering phase, especially at lower elevation angles. Biomechanically, the possibility of impinging the supraspinatus tendon against the acromion is greatest at lower elevation angles (~36–45° of humerothoracic elevation) (Bey et al., 2007). At higher angles, the tendons have rotated past the acromion and there is more bone to bone (humeral lateral edge to acromion) approximation. The serratus anterior is believed to be one of the most important muscles for scapular mobility and control (Kibler, 1998; Phadke et al., 2009) and its earlier deactivation during lowering of the arm may affect scapulothoracic motion in a detrimental way. The lack of posterior tilting and upward rotating torques normally produced by serratus anterior may alter scapular kinematics in a way as to cause further impingement of the rotator cuff tendons. All muscles showed contraction longer until the arm was lowered further in the condition with a weight in hand. This may show that during lowering of the arm, the scapular muscles need to control the scapula against the continuing torque of the deltoid acting in reverse action on the scapula which would be increased in the weighted conditions.

As compared to earlier studies which investigated latency, the current study found that there were no differences in latency of upper trapezius and serratus anterior for the unloaded condition. Lower trapezius was the last to be activated which is in agreement with Wadsworth and Bullock-Saxton (1997) who found that the lower trapezius was activated approximately after 15° of humeral elevation. No attempt was made to make a similar angular comparison in the current study as it is known that people of different sizes and body mass have a different initial humeral position at rest. A previous study (Moraes et al., 2008) used a light cue to calculate latency of trapezius and serratus anterior (absolute latency). We investigated the absolute latencies of scapular muscles in our study and found that the values obtained from both studies yield similar results for the data from healthy subjects but not so for subjects with impingement (Table 3). The Moraes et al. (2008) study found considerably higher absolute latency of lower trapezius (approximately 1–1.5 s) which might be attributed to difference in electrode placement or a lower speed of movement.

The anterior deltoid absolute latency was estimated to be 188 ms by Hodges and Richardson (1996) in a study to investigate spine muscle latency. This is less than the latency we found (281.5 ms averaged over both groups). Hodges and Richardson (1996) used an increase of 2 standard deviations from baseline as the threshold to define activation whereas our study used the criteria of 3 standard deviations. Another reason for the longer latency could be that people with shoulder pain are perhaps slower to react overall as a protective phenomenon possibly due to muscle guarding and pain. However, our study did not observe group differences for anterior deltoid latency. The variability in our study was much higher than that reported by Hodges and Richardson (1996) who in their experiment took an average of 10 trials which possibly decreased the variability of muscle latency. Only 5 trials of motion were collected under each condition in the current study.

Table 3
Mean and standard deviation for absolute latency of muscles during the unloaded condition.

	Healthy (in ms)	Impingement (in ms)
Upper trapezius	298 ± 84	312 ± 174
Lower trapezius	369 ± 160	344 ± 118
Serratus anterior	296 ± 130	327 ± 136
Anterior deltoid	265 ± 93	295 ± 109

The current study has limitations. One of the limitations was the loss of trials due to cardiac or motion artifacts. On average across conditions, the number of lost trials in each group was 7 for upper trapezius, 10 for lower trapezius and 15 for serratus anterior. The muscles were close to the chest wall and hence cardiac artifacts were observed in many trials. Also, the number of trials recommended should be higher than 5 per condition to provide a more representative average value. Other studies investigating muscle latencies have used up to 10 trials (Hodges and Richardson, 1996). As the current study was looking at more than one condition involving lifting weight for multiple repetitions (up to 15), the number of trials per condition was limited to 5 to avoid risk of further irritation and pain for subjects with impingement. The speed of motion and plane of elevation were not strictly controlled in this study. However, there were no differences found in the speed of elevation between groups, nor any moderate or strong association of speed with the dependent variables.

The electromagnetic system can interfere with the EMG data collection. Multiple notch filters were used to remove noise artifact. Also, the subjects were positioned in such a way that the electrodes were at a maximum possible distance away from the electromagnetic system. However, for obtaining data from subjects with a higher BMI, higher gains were used which amplified the signal as well as the noise from the electromagnetic system. This interference could affect the latency estimation as it may cause intermittent artifacts in the signal. It would be impossible to collect electromagnetic kinematic data simultaneously with EMG data without having these limitations and appropriate measures were taken to avoid any systematic errors between groups or conditions with the data analysis.

The ability to diagnose and treat shoulder impingement in patients who develop the pathology due to motion related abnormalities is important for clinicians. Physical therapy approaches to treatment for impingement subjects usually involves strengthening of serratus anterior, trapezius, and other rotator cuff muscles (Kuhn, 2009; Tate et al., 2010) and stretching of pectoralis minor (Borstad and Ludewig, 2005). The recommended exercises are moderately low intensity exercises not intended for muscle hypertrophy. The current study helps to identify the presence of different motor control strategies in patients. This could help therapists in choosing training protocols for selected patients with motion related abnormalities for improved outcomes.

The results of this study could help physical therapists to include in their treatment eccentric training of the serratus anterior for improved scapular control during the eccentric lowering phase in patients. As this muscle is believed extremely important for maintaining correct scapular motion on the trunk, training of this muscle especially in the lowering phase might improve the kinematic behaviors such as reducing dyskinesia and possibly decrease rotator cuff impingement. Physical therapists could also consider attempting to train patients with impingement to voluntarily reduce their upper trapezius activity before and during arm motions. Results of this study suggest that the approach of rehabilitation should be such that the outcome of therapy is not strictly focused on changes in strength (hypertrophy) but rather also consider changes in movement patterns or muscle behavior and training the appropriate motor program. The clinical benefits of such training are not proven by the current study and further research is needed. The results also suggest a need for studies to understand whether changes in kinematics and muscle activity are a cause or consequence of shoulder pain and whether serratus anterior deactivation during lowering increases the compression/abrasion of the supraspinatus tendon or reduces the tension across it.

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