Electromyographic response of shoulder muscles to acute experimental subacromial pain

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This study investigated the effects of experimentally-induced subacromial pain, induced via hypertonic saline injection, on shoulder muscles activity. Electromyographic activity of 20 healthy participants was assessed for humeral elevation and descent for the control and experimental pain conditions, using fine wire electrodes for subscapularis and supraspinatus and surface electrodes for middle deltoid, upper trapezius, lower trapezius, infraspinatus, and serratus anterior. Normalized mean amplitudes were analyzed for each muscle for four phases for elevation and descent, respectively. Repeated measures analysis of variances (ANOVAs) were used to determine differences between muscle activity in the control and experimental condition for the four phases of elevation and descent. Differences for mean normalized amplitudes were not significant during humeral elevation. Increased activity was found for the pain condition for serratus anterior and middle deltoid during the first (120–90°) and third (60–30°) parts and decreased activity for infraspinatus in the second half of descent (60–0°). No significant differences were found during descent for upper and lower trapezius, subscapularis and supraspinatus. While increased serratus anterior activity during 60–30° of descent may be protective, increased middle deltoid and decreased infraspinatus activity during the same range may threaten subacromial tissues in that range. Overall the changes in muscle activation were individual specific, particularly during the concentric elevation phase.

1. Introduction

Altered movement patterns or scapular dyskinesis are often observed in the presence of painful conditions of the shoulder, such as subacromial pain syndrome (SAP) or rotator cuff pathology (Sahrmann, 2002; Kibler and Sciascia, 2010). Clinical concepts suggest that altered muscle activation patterns of the scapulothoracic or rotator cuff muscles contribute towards the dyskinesis and development of SAP, or may develop as a consequence of such pain (Mottram, 1997; Magarey and Jones, 2003). Changes in the force couple between the lower trapezius and serratus anterior with the upper trapezius and rhomboids may contribute towards dyskinesis (Mottram, 1997). The rotator cuff muscles are accepted as dynamic stabilisers of the glenohumeral joint (David et al., 2000), and impaired function of these can also contribute towards shoulder pain (Magarey and Jones, 2003; Day et al., 2012).

Electromyography (EMG) has been used to describe changes in activation patterns of the thoraco- and humeroscapular muscles, in particular, using cross-sectional designs whereby EMG amplitudes normalized to maximum voluntary contractions (MVCs) of patients with shoulder pain are compared to healthy controls (Chester et al., 2010). EMG activity is studied typically during movements involving shoulder elevation, while holding a pre-defined hand weight or unloaded, or during isometric or isokinetic muscle contractions (Chester et al., 2010). Previous studies have indicated that, compared to healthy controls, patients with SAP had decreased serratus anterior activity during unloaded concentric elevation in the scapular plane (Ludewig and Cook, 2000; Diederichsen et al., 2009a), increased upper trapezius activity above 60° elevation (Ludewig and Cook, 2000), and increased supraspinatus and latisimus dorsi activity (Diederichsen et al., 2009a). Furthermore, Diederichsen et al. (2009a) found a tendency (P = 0.09) for increased trapezius activity for patients with SAP. A limitation of these studies is that the EMG amplitudes were normalized to MVCs.
Decreased muscle strength and voluntary activation have been demonstrated in the presence of experimental pain of the shoulder (Wassinger et al., 2012; Stackhouse et al., 2013). Loss of structural integrity due to tissue damage such as a rotator cuff tear is likely to further affect strength (Itoi et al., 1997). Thus, results of MVC-normalized EMG amplitudes for patients with painful shoulders compared to healthy painfree controls need to be interpreted with caution. To date, it is still being debated whether changes in muscle activation patterns contribute towards the development of pain in the shoulder, or whether they are consequences of the pain (Chester et al., 2010).

Experimental pain models allow assessment of the influence of pain when administered to individuals without tissue injury, such as injecting hypertonic saline into muscle or periarticular structures, creating transient local or referred pain. Following injections into two different sites, the supraspinatus and the subacromial space, Diederichsen et al. (2009b) found increased activity for latissimus dorsi and lower trapezius during concentric abduction against a load of 10% of the MVC for both these conditions, compared to the control. Serratus anterior activity was increased only following the subacromial injection. Following the supraspinatus injection, decreased activity was observed for anterior deltoid, upper trapezius and infraspinatus (Diederichsen et al., 2009b). Decreased infraspinatus activity was also found during isometric external rotation following injection into the subacromial space (Stackhouse et al., 2013). Increased serratus anterior and decreased upper trapezius activity during elevation for experimental pain conditions conflicts with those found in patients with SAP, where the opposite was found (Ludewig and Cook, 2000; Diederichsen et al., 2009a).

We have recently reported effects of experimentally induced SAP in a group of healthy individuals (Wassinger et al., 2012, 2013). Isokinetic external and internal shoulder rotation peak torque were significantly reduced by 17% and 20%, respectively, and throwing accuracy was reduced in the pain compared to the painfree condition (Wassinger et al., 2012). These data and those of the current study were collected at the same time. Increased scapular upward rotation was evident during progressive isometrically-held shoulder abduction for the painful condition (Wassinger et al., 2013). This study aims to evaluate the effects of experimentally-induced SAP on EMG variables of thoraco- and humeroscapular muscles during concentric and eccentric humeral elevation in a group of participants. Based on our previous findings of increased scapular upward rotation within the same cohort (Wassinger et al., 2013) we retrospectively hypothesized increased EMG activation of the scapulothoracic muscles (trapezius and serratus anterior) and decreased activation for the rotator cuff muscles.

## 2. Methods

Twenty healthy participants (mean age 22.3 years, range 18–31) from a University community volunteered to participate in the study, approved by the University of Otago Human Ethics Committee. All participants provided written informed consent. The participants were free of shoulder pain in the past 6 months and none had a history of seeking medical care for shoulder or neck injury at any time. These same participants also undertook tasks of isokinetic strength assessment, throwing accuracy (Wassinger et al., 2012) and clinical scapular position assessment (Wassinger et al., 2013).

Muscle activities were collected using fine wire and surface EMG. Sites for fine wire electrodes were sanitized with 70% isopropyl alcohol and 10% povidone-iodine before insertion. Single fine wire needles were prepared with a 0.05 mm nickel–chromium alloy wire with nylon insulation (California Fine Wire, Grover Beach, CA, wire 800A) and inserted intramuscularly via 1.5-in (3.81-cm) 25-gauge needles into subscapularis and supraspinatus (Kelly et al., 1997; Geiringer, 1998). Two single-wire electrodes were inserted into each muscle at an inter-electrode distance of approximately 1 cm (Kelly et al., 1997).

Muscle activity of middle deltoid, upper trapezius, lower trapezius, infraspinatus, and serratus anterior was recorded using pre-gelled silver–silver chloride surface electrodes (Medicotest Inc, Rolling Meadows, IL) and the Noraxon 2400T-G2 system (Scottsdale, AZ). Skin preparation included removing excess hair over the site, as needed, skin abrasion with emery paper, and cleaning with a 70% isopropyl alcohol. For each muscle, two surface electrodes were placed perpendicular to the orientation of the muscle fibres (Basmajian and Blumenstein, 1989). The resistance in all bipolar surface electrode pairs were measured with a multimeter and was determined be less than 10 MΩ. One surface ground electrode was placed on the superior aspect of the acromion.

Verification of EMG signal quality for the fine wire and surface electrodes was conducted by visual inspection of the raw EMG signal while subjects performed muscle-specific isometric contractions. Subjects performed a 5-s maximal voluntary isometric contraction (MVIC) against manual resistance for each muscle of interest, following standard manual muscle testing descriptions (Kendall et al. 1993).

Block counterbalancing by gender was utilized in this repeated measures crossover study (Ge et al., 2006). Male and females were randomized so that five males and five females had muscle activity measured with pain first, the control condition of no pain second, and vice versa. The experimental pain lasted approximately 20 min. The actual time while participants reported pain was not collected, however a time period of at least 20 min was allotted following completion of data collection to allow painfree testing if the experimental pain condition was completed first. The experimental testing lasted approximately 15–20 min, thus the control condition was initiated approximately 40 min following the injection for those participants performing the control condition during the second phase of data collection. Participants who completed the control condition first moved directly onto the pain condition. All testing was completed on the dominant shoulder as defined by the participant as the preferred throwing arm.

Muscle activity during a standardized humeral elevation task was recorded in conditions with and without shoulder pain. Subacromial pain was induced via injection of 2.0 mL of 5.0% hypertonic saline inserted via a 3.20 cm 23-gauge needle (Svensson and Arendt-Nielsen, 1995; Staahl and Drewes, 2004). The injection was inserted posteriorly just below the posterior aspect of the acromion by a sports physician who routinely performs subacromial injections. Pain level was monitored using a visual analog scale (VAS); participants were asked to indicate their pain rating with a vertical line along the 10 cm horizontal line, with the right side of the line indicating worst pain imaginable (Chapman et al., 1985). Pain levels were reported immediately following the EMG data collection and prior to the control condition. Pain scores ≥1.0 on the VAS scale were considered a painful condition (Tate et al., 2008).

Prior to data collection, the participant was placed facing a wall at a distance that allowed full elevation in the scapular plane, defined as approximately 30° anterior to the frontal plane with the fingers touching the wall (Myers et al., 2009), determined on visual inspection. Markers were placed on the wall in front of the subject at humeral angles of 30°, 60°, 90°, and 120° of elevation. The time for each repetition of elevation was regulated via metronome and took 4 s (2 s to elevate the arms to maximum and 2 s to return to rest) (Ludewig and Cook, 2000). The movements were constantly monitored by the investigators to ensure that they remained within the defined scapular plane. EMG and video kinematic data were
simultaneously collected during a rhythmic standardized humeral elevation task in the scapular plane. While the participant was asked to perform the humeral movement from rest to full elevation, the mean amplitude of each muscle was recorded during four phases (rest—30°, 30°—60°, 60°—90°, 90°—120°) of elevation, in line with prior research (Fig. 1) (Ludewig and Cook, 2000; Reddy et al., 2000). The mean amplitude of each muscle for each phase of elevation during 5 repetitions of humeral elevation was used for data analysis.

Raw EMG data was amplified 1000×. Frequency analysis showed less than 1% data loss from the fine wire electrodes with a low pass cut off frequency of 500 Hz, thus signals were band pass filtered between 15 and 500 Hz (4th order Butterworth) for all electrodes. Full wave rectified data was smoothed using a 50 ms RMS filter. For the MVIC, the 3 s with the greatest EMG RMS were averaged and used for normalization. The mean amplitude of each muscle for each phase of elevation during 5 repetitions of humeral elevation was normalized to the MVIC.

Two-way, repeated measures ANOVA were performed to examine main effects of the two conditions (control and experimental) and four elevation phases (rest—30°, 30°—60°, 60°—90°, 90°—120°) on the MVC normalized mean EMG amplitudes. These were performed separately for concentric elevation and eccentric descent. To determine whether there was an order effect, change scores were calculated for all participants and compared between the group performing the control condition first to that with the experimental condition first. When significant main effects were observed for the condition × phase interaction, post hoc pairwise comparisons using a Bonferroni correction were performed. The level of significance was set to \( P \leq 0.05 \).

3. Results

The participants rated pain levels as (mean, SD) 5.0 (2.7) on the VAS prior to the shoulder elevation task. No pain (0/10) was reported by any subjects during the control condition. Inspection of participants’ data showed individual-specific differences between the control and experimental pain conditions for all muscle groups (illustrated by change scores for five participants for infraspinatus during elevation, Fig. 2.1, and descent, Fig. 2.2). No significant effects for the conditions and for the condition × phase interactions were found for the EMG normalized amplitudes for all muscles during elevation (Table 1).

Significant effects were found during descent for middle deltoid (\( P < 0.001 \)) with higher amplitudes evident for the pain condition. Significant interactions for condition × phase were found for serratus anterior, deltoid and infraspinatus (Table 1). Post hoc testing for the individual phases of movement indicated increased activity for serratus anterior during the first (120°—90°) and third (60°—30°) phases for the experimental compared to the control condition, equating to mean increases from the control of 11.8 and 67.1% respectively (Table 2). Increased EMG activity was also found for the middle deltoid for the three phases from 120 to 30°. For the first phase (120°—90°) it was 27.6% higher than the control condition, 36.5% for the second phase (90°—60°) and 68.1% for the third phase (60°—30°). Decreased EMG amplitude was found for infraspinatus for the pain condition during the second half of the movement, namely 15.7% and 29.4% respectively for the phases 60°—30° and 30°—0°.

Comparing change scores for the group performing the control first to those completing the experimental condition first, no significant phase × condition interaction was evident for any muscle

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**Fig. 1.** Electrode placement during humeral elevation and descent. Surface electrodes: A: middle deltoid; B: ground electrode on the acromion; C: upper trapezius; D: infraspinatus; E: serratus anterior; F: lower trapezius. Fine wire electrodes: pre-amplifiers for G: supraspinatus; H: subscapularis.

**Fig. 2.** Change scores for electromyographic amplitudes (percentage of control condition) for five participants for infraspinatus during (2.1) elevation and (2.2) descent. Each cluster of bar graphs reflects results of an individual participant. Positive values: increase for experimental from control condition. Negative values: decrease for experimental from control condition.
group during elevation and descent. For elevation, a significant order effect ($P = 0.006$) was evident for infraspinatus with a significant difference for the fourth phase (90°C–120°C) with post hoc testing ($P = 0.016$). A significant condition effect ($P = 0.034$) was found for middle deltoid during descent, however no significant differences were evident with post-hoc testing for individual phases.

4. Discussion

Our findings indicate significantly increased serratus anterior and deltoid, and decreased infraspinatus activity for the experimental pain condition during descent from elevation, particularly from 60 to 30°C. Differences for all other muscle groups (trapezius, subscapularis and supraspinatus) were not statistically significant and large individual-specific variability was noted for all muscles included in the study, based on individual inspection of data and large SDs. The absence of significant changes for activity during concentric elevation in the current study may be explained by the unloaded condition. We previously showed that experimentally-induced subacromial pain led to decreased throwing accuracy (Wassinger et al., 2012) and increased upward rotation of the scapula during unloaded sequential isometric holds between 0 and 120°C elevation (Wassinger et al., 2013). Thus, for both of these tasks, the experimental model resulted in significant motor changes. However, those kinematic and performance-related changes did not appear to be associated with consistent changes in EMG amplitude during unloaded elevation. This may be due to greater effort to holding isometric positions compared to concentric unloaded contractions, supporting findings from previous research that differences for EMG activity with experimental pain are more likely during higher intensity movements (Bank et al., 2013). It is thus possible, that the task of the current study was not sufficiently advanced to identify differences in activity, particularly during the concentric phase.

While we did not find significant changes for muscle activity during ascent, it was interesting that the most marked findings were during the descent at the range between 60 and 30°C, namely increased activity of middle deltoid and serratus anterior, and decreased activity of infraspinatus. This contrasts with the popular belief of a painful arc existing for patients with SAP in the range above 60–120°C (Kessel and Watson, 1977). Further, recent research using bipolar fluoroscopy has described maximal compression of the supraspinatus footprint occurring in the range of 34–72° of humeral elevation in the scapular plane in young healthy individuals (Giphart et al., 2012). This is a similar humeral range of motion to the findings of altered muscle activity found in our study. Supraspinatus pain associated with elevation above 70°C may not be due to mechanical compression (Giphart et al., 2012). Thus, pain experienced with humeral elevation reported around 90°C painful arc may be more related to tensile forces within supraspinatus tendon attempting to resist the external moment arm of the humerus when it is maximal (near 90°C elevation). The reliability of fine wire EMG for rotator cuff muscles has to our knowledge, not yet been reported. However, the changes for serratus anterior and middle deltoid exceeded the intra-session minimal detectable changes of 2.4% reported recently for MVC-normalized surface EMG of humeroscapular muscles during descent from abduction (Seitz and Uhl, 2012).

### Table 1

Means (SD) of normalized EMG amplitudes of muscle groups for the painfree and experimental pain conditions during four phases of elevation and return to the starting position.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>n</th>
<th>Control condition</th>
<th>Experimental pain condition</th>
<th>Condition × phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1</td>
<td>Phase 2</td>
<td>Phase 3</td>
<td>Phase 4</td>
</tr>
<tr>
<td></td>
<td>0–30°C</td>
<td>30–60°C</td>
<td>60–90°C</td>
<td>90–120°C</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>20</td>
<td>11.8 (5.0)</td>
<td>23.1 (8.8)</td>
<td>39.4 (15.2)</td>
</tr>
<tr>
<td>Upper trapezius</td>
<td>20</td>
<td>18.2 (5.9)</td>
<td>29.1 (14.6)</td>
<td>29.9 (19.6)</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>20</td>
<td>9.7 (6.8)</td>
<td>13.6 (8.7)</td>
<td>17.8 (9.2)</td>
</tr>
<tr>
<td>Middle deltoid</td>
<td>20</td>
<td>20.1 (7.6)</td>
<td>36.1 (13.4)</td>
<td>44.8 (13.9)</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>14</td>
<td>26.1 (11.0)</td>
<td>31.0 (11.9)</td>
<td>30.6 (9.7)</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>20</td>
<td>12.7 (4.7)</td>
<td>16.8 (6.8)</td>
<td>18.0 (7.3)</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>13</td>
<td>14.9 (10.1)</td>
<td>23.2 (14.6)</td>
<td>29.4 (19.0)</td>
</tr>
</tbody>
</table>

### Table 2

Mean differences (95% confidence intervals) for pairwise comparisons for EMG amplitudes of serratus anterior, middle deltoid and infraspinatus for the four phases of return to starting position.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Phase</th>
<th>Mean differencea (95% confidence intervals)</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serratus anterior</td>
<td>Phase 1: 120–90°C</td>
<td>2.5 (0.2–4.8)</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td>Phase 2: 90–60°C</td>
<td>1.1 (−1.0 to 3.1)</td>
<td>0.278</td>
</tr>
<tr>
<td></td>
<td>Phase 3: 60–30°C</td>
<td>5.6 (2.8–8.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Phase 4: 30–0°C</td>
<td>−2.4 (−6.4 to 1.6)</td>
<td>0.233</td>
</tr>
<tr>
<td>Middle deltoid</td>
<td>Phase 1: 120–90°C</td>
<td>5.8 (2.0–9.6)</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>Phase 2: 90–60°C</td>
<td>5.3 (2.6–8.0)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Phase 3: 60–30°C</td>
<td>4.6 (2.5–6.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Phase 4: 30–0°C</td>
<td>0.5 (−0.4 to 1.4)</td>
<td>0.270</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>Phase 1: 120–90°C</td>
<td>0.0 (−1.5 to 1.6)</td>
<td>0.955</td>
</tr>
<tr>
<td></td>
<td>Phase 2: 90–60°C</td>
<td>−0.2 (−1.7 to 1.3)</td>
<td>0.744</td>
</tr>
<tr>
<td></td>
<td>Phase 3: 60–30°C</td>
<td>−1.7 (−2.9 to −0.4)</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>Phase 4: 30–0°C</td>
<td>−2.4 (−3.4 to −1.4)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a Positive mean difference: increase from the control to the experimental condition. Negative mean difference: decrease from the control to the experimental condition.
The findings of decreased activity for infraspinatus during the lower range (<60° abduction) of descent in our study would agree with past experimental pain research (Diederichsen et al., 2009b; Stackhouse et al., 2013) and with patients with SAP (Reddy et al., 2000; Myers et al., 2009; Diederichsen et al., 2009a). The decreased activity for this muscle group may at least partly explained as a consequence of pain. In patients with SAP, infraspinatus activity was reported to be decreased in the range 30–60° during concentric elevation with significant changes in coactivation ratios for the infraspinatus, subscapularis and supraspinatus compared to controls (Myers et al., 2009). As part of the rotator cuff, infraspinatus controls the glenohumeral head within the glenoid fossa during arm movements, generating a posterior/inferior force on the humeral head, which helps to resist anterior/superior humeral head translation (Escamilla and Andrews, 2005). Decreased infraspinatus activity, in the absence of similar changes for subscapularis and supraspinatus, may disturb the force couples controlling the humeral head (Ludewig and Braman, 2011), particularly in the presence of increased deltoid activity. These changes may indicate possible risk for increased superior or anterior translation of the humeral head, threatening subacromial structures and contributing towards persistence of pain. Our findings may indicate that care needs to be taken with eccentric contractions in this range for patients with SAP.

Following pain induction in the sub-acromial space, Diederichsen et al. (2009b) found increased activity of the lower trapezius, latissimus dorsi and serratus anterior during concentric abduction. While not being statistically significant for the concentric phase in the current study, our finding of increased activity for the serratus anterior during descent agrees with their findings. Serratus anterior functions as a synergist with lower trapezius, thus it was interesting that no significant difference was found for activity of the latter. Serratus anterior contributes towards scapular upward rotation, posterior tilt and external rotation while stabilizing the medial border and inferior angle (Ludewig et al., 1996). These scapular motions have been implied to provide or maintain subacromial space during humeral elevation (Ludewig et al., 2009). The middle deltoid functions as the agonist for humeral abduction and is most active during the middle part of the range of motion (ROM) (Kronberg et al., 1990). Increased serratus anterior activity is concordant with our findings of increased scapular upward rotation (Wassinger et al., 2013) and may indicate a protective mechanism by the central nervous system to decrease the increased superior shear from elicited with heightened deltoid activity or decreased humeral head compression via less infraspinatus activity (Reddy et al., 2000). Increased eccentric activity of the middle deltoid and serratus anterior during arm descent for the pain condition may also indicate greater need to control humeral descent and associated scapular downward rotation.

Clinical concepts indicate that changes in the force couples controlling scapulothoracic and glenohumeral movement may contribute towards shoulder dysfunction and pain (Mottram, 1997; Sahrmann, 2002). There is support that differences exist in EMG activity for the upper and lower trapezius for patients with SAP compared to healthy controls (Chester et al., 2010). There is also evidence that patients with SAP syndrome have decreased serratus anterior activity and increased activity for latissimus dorsi and supraspinatus (Diederichsen et al., 2009a). These findings are different to those of our experimental study, indicating possible differences in the motor control strategies in patients with injury, tissue changes and/or pain compared to healthy participants with experimental pain. It is possible that the healthy subjects are able to respond adequately to pain by using muscle activation strategies that avoid further compression of subacromial structures, particularly during elevation, while patients with SAP syndrome fail to unload these structures during movement. Alternatively, as suggested by Diederichsen et al. (2009a), differences shown in patients with SAP compared to healthy controls may contribute towards their dysfunction, rather than being consequences thereof.

Lack of EMG activity changes during elevation may be due to redistribution of activity within the muscles, both agonists and synergists (Tucker and Hodges, 2009; Bank et al., 2013; Gallina et al., 2013), or due to variability of activity with repeated trials (Madeleine et al., 2008). Increased trial-to-trial motor variability during simple, repetitive arm movements has been shown in experimental pain of upper trapezius and infraspinatus, whereas, in the same study, the variability was decreased in people with chronic pain (Madeleine et al., 2008). Large individual variability in responses found in the current study (Figs. 2.1 and 2.2) support the theory for motor adaptation to pain proposed by Hodges and Tucker (2011), namely that adaptation occurs to reduce pain and protect the painful part, involving individual- and task-specific redistribution of activity within and between muscles. An earlier pain adaptation model suggested that muscles acting as agonists to a painful movement will be inhibited while antagonistic muscles will exhibit increased activity reducing the velocity and range of painful movements (Lund et al., 1991). This was not shown to be the case in the present study with experimental pain. Careful assessment of muscle function on an individual basis thus appears to be important. A combination of assessment procedures may need to be incorporated into clinical reasoning procedures, for example, findings of observation of scapular movement, muscle strength and palpation of activity. Increased activity of the global muscles, namely deltoid and serratus anterior, during arm descent, with decreased activity of the infraspinatus in the presence of acute subacromial pain may indicate an increased risk for increased glenohumeral translation, potentially exacerbating shoulder pain.

It is possible that those receiving the experimental pain condition first had not recovered or reorganized fully before proceeding with the control condition. Diederichsen et al. (2009b) used pre- and post-control conditions, finding persistent EMG activity changes during the latter, despite resolution of pain. However, with exception for infraspinatus during elevation in the fourth phase (90–120° abduction), a significant order effect was not found for the change scores when comparing the group that received the experimental pain condition to those that had the control condition first.

As we did not use ultrasound guidance for the injection, we cannot confirm precisely which structures were targeted. Clinical landmarks described for injecting patients with sub-acromial pain (Yamakado, 2002) were used as location of injection does not determine efficacy for the management of sub-acromial pain (Hegedus et al., 2010). Furthermore, a recent review found that effects of experimental pain on various components of the motor system appear not be influenced by the source of pain (Bank et al., 2013). As all participants of this study reported experiencing pain “deep” in the shoulder, we suggest that it was most likely that, while being transient in nature, pain was induced that was similar to the pattern often reported by patients with SAP. Further, fine wire EMG records only local motor units which may not represent electrical activity within the whole muscle. While participants were asked to fully elevate their arms, EMG data above 120° abduction was not analyzed. Our results thus cannot be extrapolated to overhead activity in the upper range. Finally, the VAS was determined prior and following the abduction task, and not separately for the concentric and eccentric phases. Theoretically, differentiating the level of pain during these two phases could have contributed towards underlying changes in activity level, and should be further explored in future studies.

The participants also performed assessments of isokinetic rotator muscle strength, throwing accuracy (Wassinger et al., 2012) and isometric holds in various positions of scapulation to assess scapular
rotation [Wassinger et al., 2013]. The order of the four tasks was randomized to negate possible effects of fatigue and decreasing pain levels within a 20 min period. It is possible that the order of the tests could have influenced the EMG activity, contributing towards individual-specific changes. Finally, due to ethical considerations for the invasive methods, a small number of participants was included, which may have increased the potential for Type II error.

5. Conclusion

This study investigated the effects of experimental pain on muscle activity of thoraco- and humeroscapular muscles during unloaded concentric and eccentric elevation. Mean EMG amplitudes were not significantly different between the control and experimental pain conditions for any muscle during elevation. During descent, increased activity was found for serratus anterior and middle deltoid during the first part of movement, and decreased activity for infraspinatus in the second half of the movement, with changes for all three of these muscles during the phase from 60 to 30°. While increased serratus anterior activity during descent may be a protective response to the pain, the changes found for deltoid and infraspinatus activity may threaten subacromial tissues. Findings indicate individual-specific changes in motor control for the pain condition, particularly during the concentric phase of unloaded elevation.

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References

Chester R, Smith TO, Hooper L, Dixon J. The impact of subacromial impingement during descent may be a protective response to the pain, the changes found for deltoid and infraspinatus activity may threaten subacromial tissues. Findings indicate individual-specific changes in motor control for the pain condition, particularly during the concentric phase of unloaded elevation.