Manual Therapy xxx (2014) 1–6

Contents lists available at ScienceDirect

Manual Therapy

journal homepage: www.elsevier.com/math

Original article

Electromyographic response of shoulder muscles to acute experimental subacromial pain

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A R T I C L E I N F O

Article history:
Received 26 July 2013
Received in revised form
25 February 2014
Accepted 3 March 2014

Keywords:
Shoulder
Experimentally induced pain
Electromyography

A B S T R A C T

This study investigated 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 latissimus 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.

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http://dx.doi.org/10.1016/j.math.2014.03.001
1356-689X/

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-guage 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 $\geq$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