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Original article

Does changing the plane of abduction influence shoulder muscle recruitment patterns in healthy individuals?

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ABSTRACT

Study design: Observational laboratory study.
Background: Abduction is a movement commonly used in the assessment of shoulder dysfunction and prescription of exercises to improve shoulder function. Abduction in the scapular and coronal planes are used interchangeably. It is not known if the activation of individual shoulder muscles differ between abduction performed in these planes and therefore, if they represent different tests/exercises.
Objective: To quantify and compare the muscle activation patterns and levels for each shoulder muscle during abduction performed in the scapular plane with that performed in the coronal (scapular -30°) and scapular $+30^\circ$ planes.
Methods: Electromyographic recordings were taken from eight shoulder muscles of fourteen healthy volunteers during shoulder abduction in the scapular and coronal planes and in a plane 30° anterior to the scapular plane (scapular $+30^\circ$) at 50% of maximum load.
Results: Similar average muscle activation levels were demonstrated during abduction in the scapular plane and within a 30° arc of this plane for all muscles except: middle deltoid (5% MVC higher activation in the coronal and 4% MVC lower activation in the scapular $+30^\circ$ plane) and upper trapezius (6% MVC lower activation in the scapular $+30^\circ$ plane). Activation patterns between planes for all muscles were similar ($ICC_{(3,1)} \geq 0.87$).
Conclusions: Abduction can be performed within a 30° arc of the scapular plane with no change in shoulder muscle activation patterns. Only middle deltoid activation levels change between the scapular and coronal planes and middle deltoid and upper trapezius between the scapular and scapular $+30^\circ$ planes.

1. Introduction

Shoulder pain is one of the most common musculoskeletal problems presenting to physicians (Linsell et al., 2006) and has been reported to have the longest median recovery time of all musculoskeletal injuries Bureau of Labor Statistics and U.S. Department of Labor (2012). Effective treatment is only possible following an accurate and informed physical assessment. Abduction is a movement of the shoulder used habitually to position the hand for functional activities and is typically used in the clinical assessment of dysfunctional shoulders of unstable, stiff or painful origin (Magee, 2008). Abduction is also commonly recommended in rehabilitation and exercise programs for dysfunctional and asymptomatic shoulders to improve the function at the shoulder (Townsend et al., 1991; Moseley et al., 1992; McCann et al., 1993; Wilk et al., 2002a).

Shoulder abduction is often performed interchangeably between the scapular and coronal planes during shoulder assessment (Magee, 2008) and in rehabilitation programs (Townsend et al., 1991; Wilk et al., 2002b) but it has been suggested that the scapular plane may be the most functional plane of movement providing optimal bony and muscle alignment (Johnston, 1937; Bagg and Forrest, 1986; Alpert et al., 2000). It has also been demonstrated that there are differences in scapular, humeral and clavicular kinematics during abduction performed in the coronal plane compared to the scapular plane (Ludewig et al., 2009). However, it is not known if normal shoulder muscle recruitment

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patterns and levels are influenced if the plane in which abduction is performed varies. If shoulder abduction performed in different planes of movement does change normal recruitment of individual shoulder muscles, then these represent different tests/exercises when assessing/treating the dysfunctional shoulder or exercising the normal shoulder. No electromyography (EMG) studies have comprehensively examined muscle activity during abduction in different planes to determine if the plane in which abduction is performed influences shoulder muscle recruitment patterns in a normal subject cohort.

The aim of the current study, therefore, was to investigate the recruitment of individual muscles during active shoulder abduction performed in the scapular plane with abduction performed 30° either side of the scapular plane to determine if these movements represent different tests/exercises for shoulder muscles.

1.1. Subjects

Fourteen asymptomatic subjects (5 female and 9 male), aged between 18 and 49 years (mean age 22.5 years) volunteered for this study. To be included as asymptomatic, volunteers were required to have had no history of shoulder pain in the previous two years and to have never sought treatment for shoulder pain. Additionally, on physical examination prior to data collection, subjects had to demonstrate normal range of movement, normal scapulohumeral rhythm (assessed visually by an experienced physiotherapist) and be pain-free on isometric shoulder rotation strength tests. All but one of the subjects was right hand dominant and the dominant shoulder was studied in all cases. Subjects were fully informed of the study protocol and signed a consent form prior to participation.

1.2. Sample size analysis

A power analysis using G power software (Faul et al., 2007) was performed to calculate the sample size required for the current study. Mean activity levels recorded from middle deltoid (38 ± 11% MVC) and supraspinatus (39 ± 11% MVC) in a previous EMG study investigating shoulder abduction (Wickham et al., 2010) were chosen for this analysis as these are the muscles most responsible for producing shoulder abduction torque. With power set at 0.80, significance level set at $\alpha = 0.05$, a mean detectable difference of 6% MVC and a correlation value of 0.80, a sample size of 13 (middle deltoid data) and 14 (supraspinatus data) subjects was required. Consequently a sample size of 14 subjects was chosen for this current study. Activity levels of 10% MVC are commonly considered to represent minimal activity (McCann et al., 1993; Escamilla and Andrews, 2009; Wattanaprakornkul et al., 2011b) and correlation values of >0.90 have been demonstrated in supraspinatus and middle deltoid activity during shoulder adduction performed at different shoulder angles (Reed et al., 2010). Therefore, the mean detectable difference of 6% MVC and correlation value of 0.80 used to calculate this sample size can be considered conservative estimates.

1.3. EMG instrumentation

Eight shoulder muscles were investigated, including middle deltoid, rotator cuff muscles (supraspinatus, infraspinatus, subscapularis), and axioscapular muscles (upper and lower trapezius, serratus anterior and rhomboid major). Pairs of silver/silver chloride surface electrodes (Red Dot, 2258, 3M) were placed with centres 2 cm apart over upper trapezius and middle deltoid (Boettcher et al., 2008). The use of surface electrodes on these large superficial shoulder muscles has been shown to be valid in previous studies with minimal chance of cross talk from surrounding muscles (Giroux and Lamontagne, 1989). Prior to electrode application, the skin was prepared with abrasive gel (Nuprep, DO Weaver and Co., Aurora, US), and wiped with alcohol to reduce impedance. Inter-electrode resistance, as measured with an ohm meter, was less than 5 kΩ. Bipolar intramuscular electrodes prepared in accordance with Basmajian and DeLuca. (1985), were used to record EMG data from supraspinatus (Waite et al., 2010) and infraspinatus (Waite et al., 2010; Johnson et al., 2011) where crosstalk has been shown to significantly affect surface electrode recordings; subscapularis, a muscle inaccessible to surface electrodes; rhomboid major which lies deep to trapezius; serratus anterior where significant skin shift during dynamic movements results is underestimation of activity level (Hackett et al., 2014); and lower trapezius, a thin muscle where surface electrodes may pick up crosstalk from adjacent muscles. The skin surrounding the intramuscular insertion site was prepared with anaesthetic gel (Xylocaine 2% jelly, AstraZeneca Pty Ltd, NSW, Australia), antiseptic solution (Betadine, Faulding Healthcare Pty Ltd, Virginia, Australia) and cleaned with alcohol. This was followed by a sterile insertion procedure via a 23 gauge hypodermic needle, acting as a cannula, to place the electrodes as per the recommendations of Kadaba et al. (1992) for subscapularis and Geiringer (1994) for all the remaining muscles (experimental setup shown in Fig. 1). Indwelling electrode placements were confirmed from the EMG signals during submaximal contractions expected to produce high activity compared to contractions expected to produce low activity in the target muscles (Boettcher et al., 2008). Because of the difficulty in distinguishing between rhomboid major and lower trapezius using this method, placement of the electrodes into the rhomboid major and lower trapezius were completed with the assistance of a digital ultrasonic diagnostic imaging system (Mindray, DP-9900). A large surface ground electrode (Universal Electrosurgical Pad, 9160F, 3M) was placed over the spine and acromion of the scapula on the shoulder not being tested. The EMG signals were amplified (Iso-DAM 8 amplifiers, World Precision Instruments, Sarasota, FL; gain 100 or 1000 (depending on the signal voltage so as to not saturate the amplifier and provide good digital resolution); Common Mode Rejection Ratio: 100 dB at 50 Hz) and filtered (band pass 10 Hz to 1 kHz). Data was then transferred to a personal computer with a 16 bit analog to digital converter (1401, Cambridge Electronics Design) at a sampling rate of 2564 Hz using Spike2 software (version 4.00, Cambridge Electronics Design, Cambridge, UK).

1.4. Experimental procedure

Prior to electrode placement on the day of testing the volunteers were trained to abduct the arm from the anatomical position, leading with the thumb, through full range of abduction in the scapular plane, the coronal plane (30° posterior to the scapular plane), and scapular +30° plane (30° anterior to the scapular plane). Full range abduction was similar between planes as determined visually by an experienced physical therapist. Tape markings on the floor were used as a guide to indicate the plane of movement required and an examiner standing in each plane provided an additional visual target for the volunteer. Volunteers stood upright, looking forward with their feet comfortably spaced apart and the opposite hand rested on the adjacent hip to limit compensatory trunk movements. Speed was standardised to a count of 3 s in the concentric phase, a second at full range abduction and 3 s in the eccentric phase of abduction motion. The maximum load (100% load) able to be lifted in each plane in one repetition with no compensatory trunk or scapular movement was determined for each subject.