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Original research

Does load influence shoulder muscle recruitment patterns during scapular plane abduction?

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ABSTRACT

Objectives: Load is used to increasingly challenge muscle function and has been shown to increase muscle activity levels with no change in activation patterns during shoulder flexion, extension, adduction and rotation. However, the effect of load during shoulder abduction, a movement commonly used in assessment of shoulder dysfunction and to improve shoulder function, has not been comprehensively examined. Therefore, the purpose of this study was to determine if load influences shoulder muscle activation patterns and levels during scapular plane abduction in normal subjects.
Design: Experimental study.
Methods: Fourteen volunteers performed shoulder abduction in the scapular plane at 25%, 50% and 75% of maximum load. Eight shoulder muscles were investigated using a combination of indwelling and surface electromyographic recordings: middle deltoid, infraspinatus, subscapularis, supraspinatus, serratus anterior, upper and lower trapezius and rhomboid major.
Results: All muscles tested showed increasing average muscle activation levels with increasing load and strong correlations in the activation patterns between loads.
Conclusions: Increasing shoulder abduction load not only increases activity in middle deltoid but also in the rotator cuff (infraspinatus, subscapularis, supraspinatus) and axioscapular (serratus anterior, upper and lower trapezius, rhomboid major) muscles. The functional stabilising role of both the rotator cuff and axioscapular muscles is considered an important contribution to the increased activation levels in these muscle groups as they function to counterbalance potential translation forces produced by other muscles during shoulder abduction. The activation patterns of all shoulder muscle groups during abduction can be trained at low load and progressively challenged with increasing load.

1. Introduction

Increasing load is commonly used in shoulder rehabilitation or gym based exercise programs to progressively challenge muscles with the aim of improving strength and muscle function.[1,2] Electromyography (EMG) has been used to confirm muscle activation levels and patterns during rehabilitation exercises and it has been suggested that exercises producing low muscle activation levels be used early in rehabilitation programs[3] while higher activation levels are described as more demanding and better suited to later in rehabilitation programs.[4,5] Previous EMG studies have shown that normal shoulder muscle activation levels increase not only in the torque producing muscles but also in the rotator cuff and axioscapular muscles with increased load during dynamic shoulder flexion,[6] extension,[6] rotation[7,8] and isometric adduction.[9] Furthermore, in these studies shoulder muscle activation patterns did not change with increasing load with the same shoulder muscles recruited at low load also recruited at medium and high load. This implies that the normal recruitment pattern of muscles involved in moving and stabilising the humerus and scapula during shoulder movements can be established at low load and as load increases, all increase their activity.

Scapular plane abduction has been described as the most functional plane of shoulder abduction[2,10] and is a commonly recommended exercise used in rehabilitation and exercise programs to improve function at the shoulder.[4,5] Although shoulder muscle recruitment patterns and levels have been investigated in previous studies during scapular plane abduction at low load[1,4,11] and high load[12] significant methodological considerations such as differences in the EMG normalisation process, makes comparison between these studies at different loads invalid. Two previous EMG studies have concurrently investigated the effects of increasing

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load during scapular plane abduction; however, direct comparison between muscle activation at different loads is still problematic.[2,13] One of these studies only investigated inner range abduction (0° to 90°)[13] and neither study included load as a factor in the statistical analysis so that significant differences between muscle activation levels at different loads cannot be confirmed.[2,13] Additionally while middle deltoid and rotator cuff muscles were investigated in both studies, the only axioscapular muscle investigated was upper trapezius and only in the 0–90° abduction range.[13]

As no single EMG study has comprehensively investigated the effect of load on normal shoulder muscle activation levels and patterns during scapular plane abduction, it is still not known if increasing load during abduction systematically increases activation levels with no change in activation patterns in all shoulder muscle groups. Therefore, the aim of this experiment was to quantify and compare activation levels and recruitment patterns of middle deltoid (abduction torque producing muscle), supraspinatus, infraspinatus and subscapularis (rotator cuff muscles) and serratus anterior, upper and lower trapezius and rhomboid major (axioscapular muscles) in normal subjects through full range scapular plane abduction at low, medium and high loads.

2. Material and methods

The shoulder of the arm used for writing of fourteen asymptomatic subjects (5 female and 9 male) aged between 18 and 49 years (mean age 22.5 years) was investigated in this study. Participants had no history of shoulder pain, no pain on maximally resisted rotation tests and demonstrated full normal range of shoulder abduction (180°) with normal scapulohumeral rhythm (assessed visually by an experienced physiotherapist). The study was approved by the Human Research Ethics Committee of the University of Sydney and all subjects gave written informed consent before participating.

A power analysis using G power software[14] was performed to calculate the required sample size. Mean activity levels recorded from middle deltoid (38 ± 11%MVC) and supraspinatus (39 ± 11%MVC) in a previous EMG study investigating shoulder abduction[11] were chosen for this analysis as the muscles most responsible for producing shoulder abduction torque. With power set at 0.80, significance level $\alpha = 0.05$, 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.

Following subject familiarisation with the exercise protocol, pairs of silver/silver chloride surface electrodes (Red Dot, 2258, 3M) were placed over middle deltoid and upper trapezius[15] at an inter electrode distance of 20 mm and impedance <5 kΩ. Bipolar intramuscular electrodes[16] were used to record activity from the remaining muscles i.e. deep muscles inaccessible to surface electrodes (supraspinatus, subscapularis, rhomboid major), muscles where crosstalk (infraspinatus[17]) and geometric displacement (serratus anterior[18]) have been shown to significantly affect surface electrode recordings and thin muscles (lower trapezius) where underlying muscles could produce crosstalk. The intramuscular electrode insertion sites were prepared with an anaesthetic gel (Xylocaine 2% jelly, AstraZeneca Pty Ltd, NSW, Australia), an antiseptic solution (Betadine, Faulding Healthcare Pty Ltd, Virginia, Australia) and cleaned with alcohol. A sterile insertion technique using a 23 ga hypodermic needle as a cannula was used to place indwelling electrodes. The placement of electrodes in all muscles, except for subscapularis, were according to the recommendations of Geiringer.[19] A single bipolar electrode was placed in the midsection of subscapularis using the method described by Kadaba et al.[20] Due to the thin nature of lower trapezius and close proximity of the underlying rhomboid major, insertion of the electrodes into these muscles was guided and confirmed by a digital ultrasonic diagnostic imaging system (Mindray, DP-9900). Correct placement of the other intramuscular electrodes was confirmed by visual inspection of the raw EMG signals during submaximal contractions expected to produce moderate activity in the target muscle with low activity in adjacent muscles.[15] A surface ground electrode (Universal Electrosurgical Pad, 9160F, 3M) was placed over the spine of the scapula on the contralateral shoulder. The EMG signals were amplified and filtered (Iso-DAM 8 amplifiers, World Precision Instruments, gain = 100 or 1000 depending on the signal voltage as to not saturate the amplifier and provide good digital resolution, bandpass between 10 Hz and 1 kHz, Common Mode Rejection Ratio:100 dB at 50 Hz) before transferring 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).

Before application/insertion of the electrodes subjects were trained to abduct the arm from the side through full range of abduction in the scapular plane leading with the thumb. Feet were 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 motion. Tape markings on the floor were a guide to indicate the scapular plane of movement and an examiner standing on this line provided an additional visual target for the subject. Using dumbbell weights, the maximum load (100% load) able to be lifted in one repetition with normal scapulohumeral rhythm and no compensatory trunk movement was determined for each subject. A minimum rest interval of 30 s was given between attempts and a maximum of five attempts were required to determine the 100% load in this cohort.

Following electrode placement and signal verification, resting EMG activity was recorded for each muscle. Five standardised maximum isometric shoulder normalisation tests[15,21] were performed in sitting, three times each in random order with a 30 s break between repetitions and 2 min between tests. These included: resisted abduction at 90° abduction with humerus externally rotated; resisted extension in 30° abduction; resisted horizontal adduction at 90° flexion; resisted flexion in 125° flexion; resisted internal rotation at 90° abduction. These tests have a high likelihood of generating maximum activity in the shoulder muscles tested.[15,21]

Abduction was performed in the scapular plane while holding a dumbbell weight corresponding to 25%, 50% and 75% of maximum abduction load. Two full repetitions of shoulder abduction were completed at each load. Different load conditions were performed in random order with a 30 s break between each load condition. Synchronisation of the EMG signal with movement was achieved by a draw-wire sensor (Micro-Epsilon, WPS-1000-MK46-P10, Germany), attached to the wrist of the arm being tested.[6] If compensatory trunk or scapular movements occurred, or timing varied, the test was repeated.

EMG signals were high pass filtered (10 Hz, zero lag 8th order Butterworth), rectified then low pass filtered (5 Hz, zero lag 8th order Butterworth) using Matlab 7.1 (The Mathworks). The maximum value obtained during the normalisation tests for each muscle was used to normalise EMG recordings during shoulder abduction. The signals were time normalised over the period of the combined concentric and eccentric phases of movement (0–100% representing the duration of movement). Group mean data (±SD) for each muscle was generated from the averages of the two trials at each load. Three out of 672 signals (14 subjects × 3 loads × 8 muscles × 2 trials) or less than 1% of data was eliminated due to electrode