The rotator cuff muscles are activated at low levels during shoulder adduction: an experimental study

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Question: During isometric shoulder adduction in normal subjects, do the rotator cuff muscles activate more than other shoulder muscles? Are the activation patterns influenced by shoulder abduction angle or load? Design: A within-participant, repeated measures experimental study. Participants: 15 healthy adults. Intervention: Participants performed an isometric adduction exercise at 30°, 60°, and 90° abduction in the scapular plane and at 25%, 50%, 75%, and 100% load. Outcome measures: During the exercises, a combination of indwelling and surface electromyographic recordings were taken from 11 shoulder muscles: supraspinatus, infraspinatus, subscapularis, pectoralis major, teres major, rhomboid major, serratus anterior, lower trapezius, upper trapezius, and deltoid. Results: At 100% load, mean rotator cuff activation levels were low (supraspinatus at 3% of its maximum voluntary contraction, infraspinatus 27%, and subscapularis 27%) and significantly less than the activation levels of rhomboid major (81%), latissimus dorsi (103%), and teres major (76%) (F_{1,14} = 15.5, p < 0.01). No significant difference in activity levels of the rotator cuff muscles were recorded when isometric adduction was performed at 30°, 60°, or 90° abduction (p > 0.89). Among the muscles activated above minimum levels (> 10% of maximum voluntary contraction), mean activation levels increased as load increased (F_{5,60} = 72.0, p < 0.01) Conclusion: Since isometric adduction in normal subjects does not produce moderate to high activation levels in any of the rotator cuff muscles tested, these results do not support the use of shoulder adduction to identify rotator cuff muscle dysfunction or strengthen the rotator cuff muscles. [Reed D, Halaki M, Ginn K (2010) The rotator cuff muscles are activated at low levels during shoulder adduction: an experimental study. Journal of Physiotherapy 56: 259–264]

Key words: Adduction, Rotator cuff, Shoulder, Isometric, Electromyography, Recruitment pattern

Introduction

The rotator cuff muscles have long been recognised as integral to the normal functioning of the shoulder. They act as prime movers of the glenohumeral joint rotating it internally and externally (Basmajian and DeLuca 1985, Jenp et al 1996, Kelly et al 1996). They also stabilise the glenohumeral joint by providing a medial (Inman et al 1944, Sharkey et al 1994), inferior (Hurschler et al 2000, Inman et al 1944, Sharkey and Marder 1995), anterior, and posterior force (Kronberg et al 1990) on the humeral head keeping it central in the glenoid fossa during shoulder joint movement.

Adduction exercises are commonly recommended in the diagnosis and treatment of rotator cuff dysfunction (Allingham 1995, Allingham 2000, Morrison et al 1997, Reinold et al 2004). This is based on clinical observation, which suggests that adduction activates and strengthens the rotator cuff (Allingham 1995, Allingham 2000, Morrison et al 1997), increasing the depressive role of the rotator cuff on the head of the humerus without activating the superior translation forces of deltoid (Morrison et al 1997, Reinold et al 2004). Additionally, when adduction is combined with external rotation it is thought to increase the contraction of the posterior cuff (supraspinatus, infraspinatus, teres minor) in their rotational role, providing greater potential for strengthening this portion of the rotator cuff (Wilk et al 2002). Adduction with external rotation also reduces activity in middle deltoid (Bitter et al 2007).

Data from magnetic resonance imaging during active shoulder adduction indicate that muscle activity leads to a significant increase in the size of the subacromial space due to inferior translation of the humeral head (Graichen et al 2005, Hinterwimmer et al 2003). It is not known, however, whether this inferior humeral head translation is due to rotator cuff muscle activity because rotator cuff activity during adduction has not been directly measured using electromyography. Force studies indicate that latissimus dorsi, pectoralis major and teres major have much larger depressive moment arms during adduction than the rotator cuff muscles (Hughes and An 1996, Kuechle et al 2005, Hinterwimmer et al 2003). It is not known, however, whether this inferior humeral head translation is due to rotator cuff muscle activity because rotator cuff activity during adduction has not been directly measured using electromyography. Force studies indicate that latissimus dorsi, pectoralis major and teres major have much larger depressive moment arms during adduction than the rotator cuff muscles (Hughes and An 1996, Kuechle et al 2007). Furthermore, we are unaware of any clinical trials evaluating the effectiveness of isolated adduction exercises in the treatment of rotator cuff dysfunction. Therefore, the validity of the use of adduction exercises to diagnose and treat rotator cuff dysfunction remains unknown.

Thus the aim of this study was to electromyographically compare activity in the rotator cuff and other shoulder muscles during adduction. The specific questions addressed in this study were:

1. During isometric shoulder adduction in the scapular plane, are there differences between the activation levels of supraspinatus, infraspinatus, and subscapularis (rotator cuff muscles); pectoralis major, teres major and latissimus dorsi (muscles that have a primary function to adduct the shoulder); rhomboid major, serratus anterior, and trapezius (axiospacual muscles); and deltoid (an antagonist to adduction)?
2. Are these activation levels influenced by abduction angle?
3. Are these activation levels influenced by load?
Method

Design
A within-participant, repeated measures experimental study of shoulder muscle activation during adduction was carried out with adult participants who did not have shoulder pain. Electrodes for electromyography were attached to 11 shoulder muscles: supraspinatus, infraspinatus, subscapularis, pectoralis major, teres major, latissimus dorsi, rhomboid major, lower trapezius, upper trapezius, serratus anterior, and deltoid. Initially, a maximum voluntary contraction was elicited from each muscle group for later comparison. Participants then isometrically adducted their shoulder at three angles (30°, 60°, and 90° of shoulder abduction) at four loads (25%, 50%, 75%, and 100% of maximum load).

Participants
Adults were eligible to participate in the study if they had no history of shoulder pain in the previous two years and had never sought treatment for shoulder pain. Prior to commencement of data collection, a physical examination of the test shoulder was performed. Participants were excluded if they did not demonstrate normal range of movement and normal scapulohumeral rhythm, or if they had any pain on isometric rotation strength tests.

Intervention
To establish maximum voluntary contraction in each of the 11 shoulder muscles, four Shoulder Normalisation Tests were performed. These tests have previously shown to have a high likelihood (95% chance) of generating maximum electromyographic activity in the shoulder muscles tested (Boeticher et al. 2008). Each Shoulder Normalisation Test was performed three times with at least 30 seconds rest between each repetition. The order of the tests was randomised to avoid systematic effects of fatigue.

Each participant stood in an upright posture with the scapula retracted. The shoulder to be tested was positioned in the scapular plane (30° in front of the coronal plane of the body) at the shoulder abduction angle to be tested. Isometric adduction testing was performed in random order at 30°, 60°, and 90° abduction. The opposite hand rested on the opposite hip to prevent compensatory trunk movements during the adduction tests. The participant held a handle attached to a force transducer and then exerted an adduction force displayed to the participant on an oscilloscope (Figure 1). Target forces, corresponding to 25%, 50%, 75%, and 100% of the participant’s maximum isometric adduction force at each of the three abduction angles (determined prior to the insertion of electrodes), were displayed on an oscilloscope. Participants were instructed to adduct the arm isometrically to match the target and were required to build up to the target force during the first second, hold it for three seconds, then release slowly over the final second. In total, 12 conditions were tested in random order, ie, contractions at 25%, 50%, 75%, and 100% of the maximum load were each performed at 30°, 60°, and 90° abduction. Two repetitions of each condition were performed.

A combination of surface electrodes and indwelling electrodes was used to record electromyographic data from eleven sites around the shoulder simultaneously. Paired silver/silver chloride surface electrodes placed 2 cm apart were used to record from pectoralis major, upper trapezius, and middle deltoid. Intramuscular hook-wire electrodes prepared in the laboratory in accordance with Basmajian and DeLuca (1985) were inserted into rhomboid major, lower trapezius, infraspinatus, supraspinatus, subscapularis, teres major, latissimus dorsi, and serratus anterior in that sequence using a 23 gauge needle as a cannula. Insertion sites of the indwelling electrodes were in accordance with the recommendations of Kabada and colleagues (1992) for subscapularis, and Geiringer (1994) for all remaining muscles. Correct electrode placement, in the majority of muscles examined, was confirmed by comparing the signals during submaximal contractions expected to generate high levels of activity in the target muscle, to contractions expected to produce low activity in the target muscle or to activate surrounding muscles into which the intramuscular electrode may have been inserted incorrectly. Because of the difficulty in distinguishing between rhomboid major and

Figure 1. Experimental setup for isometric adduction at 90° abduction in the scapular plane.
lower trapezius using this method, intramuscular electrodes were inserted into these muscles using an ultrasonically guided insertion technique. Following insertion of the indwelling electrodes, the shoulder was moved passively to determine the extent of wire excursion through the skin during the abduction range of movement required for the testing procedure. Allowing for this excursion, all wires were then looped and taped to the skin to prevent accidental removal and to reduce movement artefact during the testing procedure. A large surface ground electrode was placed over the spine and acromion of the scapula of the opposite shoulder (Figure 1). The EMG signals were amplified and filtered (gain = 100, bandpass between 10 Hz and 1 kHz) before transferring to a personal computer with a 16 bit analog to digital converter at a sampling rate of 2564 Hz.

**Data analysis**

Electromyographic signals were high pass filtered, rectified, and low pass filtered. These values were then expressed as a percentage of the maximum value of the filtered electromyographic signal generated for each muscle during the Shoulder Normalisation Tests. Mean electromyographic data for each muscle for each participant were calculated at each test position and each load by averaging a 1-sec sample from the two trials conducted. Group mean (SD) electromyographic data were subsequently calculated.

A 3-factor, repeated measures ANOVA was performed to compare the levels of electromyographic activity across the 11 muscles, 3 angles, and 4 loads. Statistical significance was set at \( p < 0.05 \). Tukey post hoc analysis with pairwise comparisons was used to identify specific differences when significant ANOVA results were obtained.

**Results**

**Characteristics of participants**

Fifteen people participated in the study. They were aged between 18 and 49 years (mean 22), with 9 being male and 6 female. All but one of the participants were right hand dominant and the dominant shoulder was studied in all cases.

**Compliance with the intervention**

All participants completed all 12 conditions. The raw electromyographic signals were examined visually and only 0.5% (representing 20 trials out of a total of 3960) of the data was discarded from further analysis due to technical issues, such as signal failure which occurred randomly across trials during the experiment.

**Activation of shoulder muscles during adduction**

In order to illustrate the maximum contribution of each of the shoulder muscles during adduction, the mean (SD) activation level measured during isometric adduction at 100% load was expressed as a percentage of the maximum voluntary contraction for each muscle. These data are shown in Figure 2 for angles of 30°, 60°, and 90° shoulder abduction. There was a significant difference in the mean activation levels between muscles across all loads and angles (\( F_{10,146} = 15.5, p < 0.01 \)). The mean activity levels during adduction at all loads in teres major, latissimus dorsi, and rhomboid major were similar (all pairwise comparisons \( p > 0.27 \)) and significantly higher than the mean activity levels of supraspinatus, infraspinatus, subscapularis, pectoralis major, serratus anterior, lower and upper trapezius, and middle deltoid (all pairwise comparisons \( p < 0.05 \)). Furthermore, there was no significant difference in activation levels within this group of lower activated muscles (all pairwise comparisons \( p \geq 0.6 \)).

The mean muscle activation levels for all muscle sites examined at each load level during isometric adduction performed at 30°, 60°, and 90° shoulder abduction are illustrated in Figure 3. For the muscles activated above minimum levels (> 10% of maximum voluntary contraction) mean activation levels differed significantly between loads (\( F_{3,42} = 72.0, p < 0.01 \)) which post hoc testing revealed to be a systematic increase with load (\( p < 0.01 \)). There was a significant angle effect (\( F_{2,28} = 5.1, p = 0.01 \)), with greater levels of activation at 30° than at 90° abduction (\( p < 0.01 \)). There was a significant interaction in the activation pattern of muscles at different angles (\( F_{20,280} = 3.2, p < 0.01 \)). Post hoc testing revealed greater activation in latissimus dorsi and teres major at 30° compared to 90° abduction (\( p < 0.01 \)). There were no significant differences across different angles of shoulder abduction in the electromyographic activation levels in any other muscles (all pairwise comparisons \( p > 0.89 \)). There was also a significant interaction between muscles, angles and loads (\( F_{60,840} = 1.4, p = 0.04 \)). However, when the muscles that were activated to less than 10% of their maximum voluntary contraction (ie, supraspinatus, pectoralis major, upper trapezius, deltoid) were removed from the analysis there was no significant difference in the activation pattern of the remaining muscles (\( F_{6,504} = 1.2, p = 0.16 \)) indicating similar activation patterns in the active muscles.
This is the first study to comprehensively examine shoulder muscle activity during isometric shoulder adduction in positions commonly used by clinicians. Results indicate that during isometric adduction in the scapular plane, the three rotator cuff muscles examined were activated at low levels with no significant difference in activity levels in these muscles when isometric adduction was performed at 30°, 60°, or 90° abduction. At maximum (100%) load, supraspinatus activity was negligible while infraspinatus and subscapularis had activity that was only about one-quarter of their maximal activation. In contrast, high mean activation levels were recorded in teres major, latissimus dorsi, and rhomboid major under the same load. These levels were significantly higher than the rotator cuff activation levels. The results of the current study, therefore, do not support the clinical observation that adduction preferentially recruits the rotator cuff muscles or activates them at substantial levels.

The high level of latissimus dorsi and teres major activity recorded in the current study support the results of force studies (Hughes and An 1996, Kuechle et al 1997) and electromyographic studies (Broome and Basmajian 1971, Jonsson et al 1972), which indicate these muscles are major contributors to adduction torque. However, although force studies have indicated that subscapularis (Kuechle et al 1997) and infraspinatus (Hughes and An 1996) have favourable moment arms to contribute to adduction torque, the results of the current study provide electromyographic evidence that this contribution is small. Therefore, the relative increase in the subacromial space occurring during adduction as shown by magnetic resonance imaging studies (Graichen et al 2005, Hinterwimmer et al 2003) is not likely to be caused by these rotator cuff muscles but rather by latissimus dorsi and teres major.

The results of the current study do not support the use of shoulder adduction as an optimal exercise to strengthen the rotator cuff muscles. Reinold and colleagues (2004) have suggested that optimal strengthening exercises require high levels of activity from the target muscle while minimising surrounding muscle activity. Muscle activity levels greater than 50% of their maximum voluntary contraction have previously been categorised as high and challenging to a muscle (McCann et al 1993, Townsend et al 1991). Shoulder adduction does not generate high levels of activity in any of the rotator cuff muscles tested and it does generate very high levels of activity in latissimus dorsi and teres major as well as rhomboid major. As an exercise to strengthen the rotator cuff muscles, shoulder adduction therefore fails to meet both these criteria for an optimal strengthening exercise, regardless of the functional role the rotator cuff may be performing.

In addition, the results of the current study do not support the use of an adduction manoeuvre to identify rotator cuff...
The minimal to low activation of the rotator cuff muscles during isometric adduction lends little support to the classic explanation, based on clinical observation, that a decrease in shoulder impingement pain associated with an adduction manoeuvre, occurs due to activation of the rotator cuff muscles in their role as depressors of the humeral head (Allingham 1995, Allingham 2000, Morrison et al 1997). A more credible explanation of the decrease in pain observed clinically during resisted adduction would seem to be related to deltoid inactivity. As expected, even at 100% load the deltoid was working at a negligible level during isometric adduction and thus not generating a superior translatory force on the humeral head. Such a force could potentially cause pain due to impingement of structures between the humeral head and the acromion or coracoacromial ligament (Sharkey and Marder 1995).

There are a number of other plausible explanations for the low activation levels recorded in subscapularis and infraspinatus in the current study. Their equal activation suggests that they may be providing a medial compressive force (Poppen and Walker 1978, Sharkey et al 1994) to stabilise the shoulder joint with a balanced anterior and posterior component. Alternatively, the activation in infraspinatus could be explained by the need to cancel out unwanted shoulder internal rotation that latissimus dorsi and teres major activity might otherwise produce. Finally, subscapularis activity may be contributing to shoulder joint dynamic stability by providing an anteriorly directed translatory force to counterbalance the posterior translation of the humeral head, again caused by latissimus dorsi and teres major activity.

Another significant finding of the current study was that against a constant load latissimus dorsi and teres major recorded significantly greater activation levels at 30° abduction than at 90° abduction. The greater activation may be explained by the more favourable length-tension relationship of these muscles at this lower abduction angle compared to higher angles, enabling greater torque production. This finding would indicate that a change in angle during isometric adduction may enhance the training potential for latissimus dorsi and teres major.

The minimal activity levels recorded in pectoralis major (10% of maximum voluntary contraction) in the current study were not expected. Previous electromyographic studies (Basmajian and DeLuca 1985, Jonsson et al 1972) and force studies (Hughes and An 1996, Kuechle et al 1997) have indicated that pectoralis major contributes to shoulder adduction performed in the scapular plane. An explanation for this unexpected finding might relate to the decision to use a single pair of surface electrodes, placed where the two heads overlap, to record pectoralis major activity in the current study. This electrode placement may not have been optimal to detect activity in the deeper sternal head which is more likely to be activated in adduction. The use of two pairs of surface electrodes, in future research, to record activity in the clavicular and sternal heads of pectoralis major separately could clarify this issue.

The only axioscapular muscle to record high mean levels of activity in the current study was rhomboid major. This result was expected since scapula downward rotation accompanies adduction and rhomboid major generates scapular torque in a downward rotation direction and into retraction (Oatis 2009). The level of activity recorded in rhomboid major in the current study supports previous research, which reported similar levels during manual muscle testing with a manoeuvre involving adduction (Smith et al 2004). Activity in serratus anterior, the only other axioscapular muscle to be activated above minimal levels in this study, may be present to prevent rhomboid major from retracting the scapula during isometric adduction or to hold the scapula against the thoracic wall.

The pattern of increasing muscle activation with increased load was the same across all angles for all the active muscles in the current study. Muscles recruited at low loads during isometric adduction are the same muscles recruited at higher loads but at a higher percentage of their maximum voluntary contraction. Additional muscles are not activated to cope with the additional load. This seems to contradict the ‘law of minimal muscle action’, proposed by MacConaill and Basmajian (1977), which states that ‘the muscles with least synergistic activity will be recruited first and then as load increases other muscles are recruited’. Similar motor patterns at low and high load with systematic increases in activity in all active shoulder muscles have been demonstrated previously in normal participants during isometric shoulder rotation exercises (Dark et al 2007), isotonic scaption exercises up to 90° (Alpert et al 2000) and shoulder flexion exercises. This study adds to the evidence that normal shoulder motor patterns do not vary with load.

Footnotes:

1BCM sensor, model 6917, capacity 50 kg.
2Pararemeters, 20 MHz oscilloscope, 3502. Red Dot, 2258, 3M.
3Mindray, DP-9900, digital ultrasonic diagnostic imaging system.
4Universal ElectroSurgical Pad, 9160F, 3M.
5ISO-DM 8 amplifiers, World Precision Instruments. 1401, Cambridge Electronics Design.
6Spike2 software, version 4.00, Cambridge Electronics Design. 80 Hz, zero lag 8th order Butterworth.
7Hz, zero lag 8th order Butterworth.
8Statistica, version 7.1, Stasoft.

Ethics: Participants were fully informed of the study protocol and signed a consent form prior to participation. The study was approved by The University of Sydney Human Research Ethics Committee.

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