Journal of Electromyography and Kinesiology 23 (2013) 425–429

Contents lists available at SciVerse ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Does supraspinatus initiate shoulder abduction?

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ARTICLE INFO

Article history:
Received 21 August 2012
Received in revised form 22 October 2012
Accepted 12 November 2012

Keywords:
Shoulder
Rotator cuff
Muscle activation
Timing
Electromyography

ABSTRACT

Purpose: It is commonly stated that supraspinatus initiates abduction; however, there is no direct evidence to support this claim. Therefore, the aims of the present study were to determine whether supraspinatus initiates shoulder abduction by activating prior to movement and significantly earlier than other shoulder muscles and to determine if load or plane of movement influenced the recruitment timing of supraspinatus.

Methods: Electromyographic recordings were taken from seven shoulder muscles of fourteen volunteers during shoulder abduction in the coronal and scapular planes and a plane 30° anterior to the scapular plane, at 25%, 50% and 75% of maximum load. Initial activation timing of a muscle was determined as the time at which the average activation (over a 25 ms moving window) was greater than three standard deviations above baseline measures.

Results: All muscles tested were activated prior to movement onset. Subscapularis was activated significantly later than supraspinatus, infraspinatus, deltoid and upper trapezius, while supraspinatus, infraspinatus, upper trapezius, lower trapezius, serratus anterior and deltoid all had similar initial activation times. The effects of load or plane of movement were not significant.

Conclusions: Supraspinatus is recruited prior to movement of the humerus into abduction but not earlier than many other shoulder muscles, including infraspinatus, deltoid and axioscapular muscles. The common statement that supraspinatus initiates abduction is therefore, misleading.

1. Introduction

Despite evidence from both 'in vivo' (Howell et al., 1986; McCully et al., 2007; Van Linge and Mulder, 1963) and 'in vitro' (Thompson et al., 1996) studies dating back to 1963, that paralysing supraspinatus does not impede the ability to abduct the shoulder, it is still universally reported in anatomy textbooks that supraspinatus initiates shoulder abduction (Moore and Dalley, 2006; Palastanga et al., 2008; Standring, 2008). Numerous studies confirm that supraspinatus is active during the full range of shoulder abduction (Basmajian and DeLuca, 1985; Inman et al., 1996; Kronberg et al., 1990) however, there is no direct evidence to support the claim that supraspinatus initiates abduction.

For a muscle to act as an initiator of a movement it must activate prior to other muscles moving that joint and prior to the movement occurring in order to generate enough tension to produce the movement, or in the case of the shoulder joint, to dynamically stabilise the joint. Therefore, to investigate the claim that supraspinatus initiates shoulder abduction, direct evidence is required to indicate that supraspinatus is activated prior to the activation of other shoulder muscles and prior to the beginning of the abduction movement. Only one electromyographic (EMG) study has compared the onset of muscle activity in supraspinatus with other shoulder muscles during shoulder abduction in asymptomatic participants (Wickham et al., 2010). These authors concluded that supraspinatus initiates abduction, reporting that deltoid, middle trapezius as well as supraspinatus were activated prior to the commencement of the abduction movement but found no significant difference in onset of activity between supraspinatus and seven other shoulder muscles examined: middle, anterior and posterior deltoid, middle and upper trapezius, serratus anterior and rhomboid major (Wickham et al., 2010). Wickham et al. (2010) determined the initiation of muscle activation by the subjective method of visual inspection of the data signals to identify the first detectable point where the EMG signal rose above the baseline. An objective and more reliable method of determining muscle activation onset time is by the use of an algorithm (Di Fabio, 1987; Hodges and Bui, 1996), which has been utilised by other researchers investigating onset of muscle activity in the back (Hodges and Richardson, 1996), around the knee (Bennell et al., 2010) and at the shoulder (Barden et al., 2005; Brindle et al., 2007; Santos et al., 2007). It remains to be determined if significant differences would be revealed in the timing of supraspina-

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1050-6411/$ - see front matter
http://dx.doi.org/10.1016/j.jelekin.2012.11.008

tus activation – compared to the activation of other shoulder muscles and the commencement of movement into shoulder abduction – if this more objective criterion for determining the onset of muscle activity was applied.

The aim of the current experiment, therefore, was to determine, using an objective measure of the initial muscle activation timing, if supraspinatus initiates shoulder abduction based on whether it is activated prior to the activation of other shoulder muscles and prior to movement of the upper limb during abduction. Secondary aims were to determine if load or plane of movement affected supraspinatus initial activation timing.

2. Methods

2.1. Participants

The dominant shoulder (13 right and one left) of fourteen asymptomatic volunteers (five female and nine male), aged between 18 and 49 years (mean 22.5 years) was tested in this study. All volunteers were involved in recreational sporting activities, had no history of shoulder pain in the previous 2 years and had never sought treatment for shoulder pain. In addition, they were required to demonstrate normal range of shoulder movement (0–180°), with normal scapulohumeral rhythm, assessed visually by an experienced physiotherapist, and be pain-free during maximal isometric shoulder rotation tests. Informed consent was obtained and the study was approved by the University of Sydney Human Research Ethics Committee.

2.2. Instrumentation

Activity was recorded from seven muscle sites around the dominant shoulder using a combination of surface and fine wire intramuscular electrodes (Fig. 1). Paired silver/silver chloride surface electrodes (Red Dot, 2258, 3 M) were placed at a distance 2 cm apart over upper trapezius and middle deltoid. Studies indicate that the use of surface electrodes to record activity from these large, superficial muscles is valid i.e. unlikely to be affected by crosstalk from surrounding or underlying muscles (Giroux and Lamontagne, 1990; Oberg et al., 1992). Bipolar intramuscular electrodes were used to record activity in deep muscles inaccessible to surface electrode recordings (supraspinatus, subscapularis), in serratus anterior which may shift position in relation to the skin during shoulder abduction, and in the thin lower trapezius where surface electrodes may pick up underlying muscle activity. In addition, an indwelling electrode was used to record activity from infraspinatus where the use of surface electrodes has been shown to result in significant crosstalk from surrounding muscles in some shoulder movements (Johnson et al., 2011). The intramuscular electrodes were prepared in accordance with Basmajian and DeLuca (1985) and placement followed the recommendations of Geiringer (1994) for all but the subscapularis which was inserted according to Kadaba et al. (1992). A digital ultrasonic diagnostic imaging system (Mindray, DP-9900) was used to accurately place the electrodes into lower trapezius. All indwelling electrode placements were confirmed by visual inspection of EMG signals during the performance of standardised submaximal tests expected to produce high activity in the target muscle and compared with tests expected to generate low activity or to activate surrounding muscles into which the electrode may have been incorrectly placed (Boettcher et al., 2008). 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 and filtered (Iso-DAM 8 amplifiers, World Precision Instruments, gain = 100, bandpass filtered between 10 Hz and 1 kHz) before transferring to a personal computer with a 16 bit analogue to digital converter (1401, Cambridge Electronics Design) at a sampling rate of 2564 Hz using Spike2 software (version 4.00, Cambridge Electronics Design).

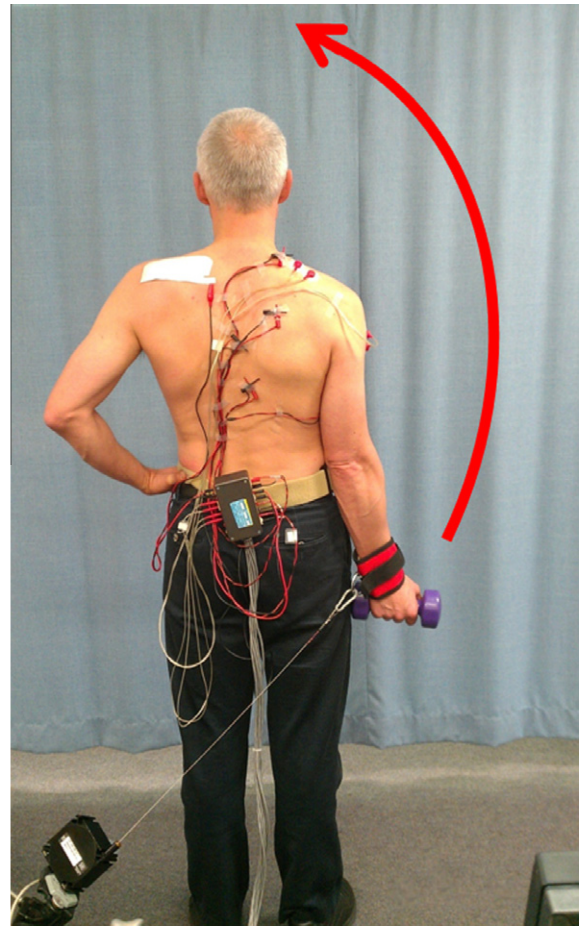

Fig. 1. Experimental setup.

2.3. Experimental protocol

Abduction testing was performed in the coronal, scapular (30° anterior to the coronal plane of the body), and the scapular +30° (30° anterior to the scapular plane of the body) planes using visual cues to guide the plane of the movement. Participants stood upright with feet shoulder width apart and the opposite hand resting on the adjacent hip to limit compensatory trunk movements (Fig. 1). Prior to testing, they were trained to abduct the dominant arm from the anatomical position, with the thumb pointing outward in the line of the movement and leading the arm through full range of movement over a 3 s period. The maximum abduction load able to be lifted in one repetition using normal scapulohumeral rhythm was determined as maximum load.

During testing, the participants performed full range abduction, as previously practiced, with the dominant shoulder in each of the three planes while holding a dumbbell corresponding to 25%, 50% or 75% of maximum abduction load, for a total of nine repetitions. All conditions were randomised to minimise effects of fatigue. The beginning of movement was determined from a draw wire sensor (Micro-Epsilon, WPS-1000-MK46-P10, Germany), attached to a cuff on the wrist of the arm being tested. An experienced observer monitored exercise performance to ensure that correct scapulohumeral rhythm without compensatory trunk movement and correct timing of movement was maintained throughout range.

2.4. Data analysis

The EMG signals were high pass filtered (10 Hz, zero lag 8th order Butterworth), rectified and low pass filtered (50 Hz, zero lag 8th order Butterworth) using Matlab 7.1 (The Mathworks). Two out of 252 signals (<1%) were eliminated due to electrode failure: in one shoulder in subscapularis and in another shoulder in serratus anterior. A baseline EMG level for each muscle in each trial was determined from a 500 ms segment before the abduction movement began, with the participant resting in the anatomical position and holding the specified weight for the trial. Initial activation timing of a muscle was determined by an algorithm (Matlab 7.1) as the midpoint of the first 25 ms moving window in which the average muscle activity was greater than three standard deviations above this baseline measure (Hodges and Bui, 1996). Taking into account both negative and positive influences of different parameters, Hodges and Bui (1996) identified that low pass filtering the EMG signal at 50 Hz using a moving window of 25 ms which the mean must exceed a threshold of three standard deviations above baseline accurately represents the time of the onset of EMG activity. Additionally, using these parameters, this method of evaluating the onset of activation timing has been shown to be highly repeatable with an intraclass correlation of 0.91 (95%CL 0.67–0.98) (Cowan et al., 2000). The start of movement for each trial was determined from the velocity of the draw wire sensor trace as the first point at which the slope of the velocity first deviated from zero. The initial activation timing was then calculated as the time from the start of movement to the initial muscle activation, with negative values indicating activation prior to the start of movement. Group mean (±95% confidence intervals) initial activation timing was calculated for each muscle at each load.

A three factor repeated measures ANOVA was performed to compare the average initial activation times across the seven muscles, three planes and three loads (Statistica, version 7.1, Statsoft). Statistical significance was set at $p < 0.05$. Tukey post hoc test was used to identify specific differences when significant ANOVA results were obtained.

3. Results

A sample of the high pass filtered and rectified EMG signals overlaid with the low pass filtered signals from the seven muscles tested and the draw wire signal of a typical subject through the full range of shoulder abduction performed in the scapular plane is shown in Fig. 2. There was a significant difference in the time of initial activation between muscles across all loads and planes ($F_{6,72} = 7.15$, $p < 0.001$). There was no significant difference however, in the effect of load ($F_{2,24} = 1.19$, $p = 0.32$) and plane ($F_{2,24} = 0.98$, $p = 0.39$) on the time of initial muscle activation. There were also no interactions between muscles, planes or loads ($p > 0.18$). Tukey post hoc testing revealed that subscapularis was activated significantly later than supraspinatus, infraspinatus, middle deltoid and upper trapezius ($p < 0.05$) by an average of 0.08 ± 0.01 s, but no other differences in onset of muscle activation were found. All muscles tested were activated prior to movement onset. The average onset of muscle activity in the seven muscles examined, across the three planes and three loads, in relation to the onset of the shoulder abduction movement are shown in Fig. 3.

4. Discussion

This is the first study to apply a highly repeatable, objective method to determine the onset of muscle activity during shoulder abduction. The results clearly show that supraspinatus does not activate alone during the initiation of abduction. All seven shoulder

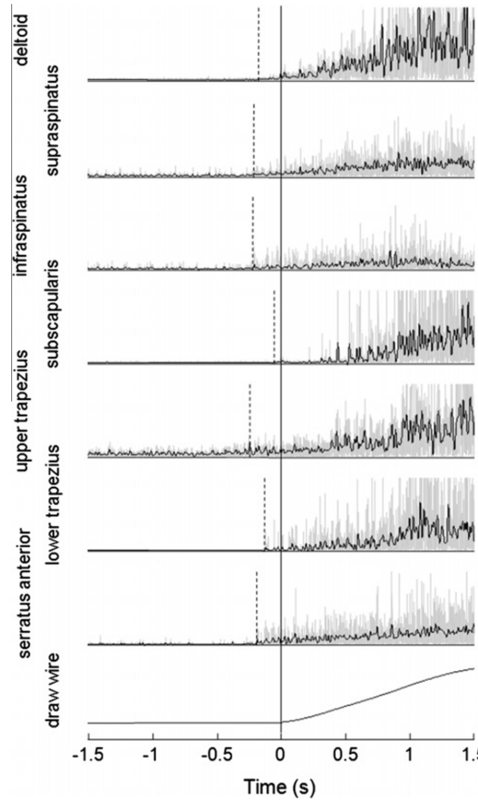

Fig. 2. A sample of the high pass filtered/rectified EMG signals overlaid with high pass/rectified/low pass filtered signals from the seven muscles examined and draw wire signal during 75% max trial from a typical subject showing the start of movement (solid line at time = 0 s) and the initiation of the activation of each muscle (dotted lines).

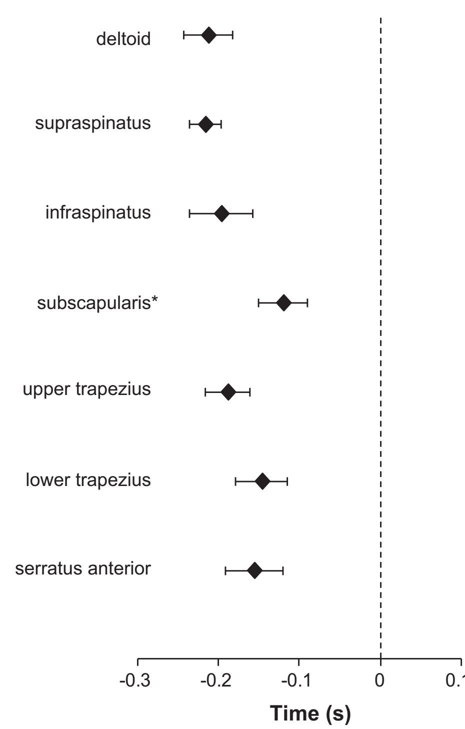

Fig. 3. Average initial muscle activation times (±95% confidence intervals) of the seven muscles during shoulder abduction across all planes and loads. Onset of movement occurred at 0 s indicated by the vertical line. * Significantly later initial onset of subscapularis compared to supraspinatus, infraspinatus, upper trapezius and deltoid.

muscles investigated in this study activated prior to the onset of movement of the humerus during abduction in the coronal, scapular and scapular +30° planes, with no significant differences in the onset of activity between supraspinatus, infraspinatus, middle deltoid, upper trapezius, lower trapezius and serratus anterior. This pattern was not affected by plane or load and demonstrates unequivocally that many shoulder muscles are contracting simultaneously at the initiation of shoulder abduction, reflecting the complex pattern of co-ordinated muscle activity required to produce shoulder movement. Based on the definition that an initiator of a movement is a muscle that activates prior to other muscles and prior to movement, it is therefore misleading to refer to supraspinatus as 'the initiator of abduction'.

An EMG study of shoulder flexion, investigating twelve shoulder muscles, including the seven muscles investigated in the current study, found that only supraspinatus, infraspinatus and anterior deltoid were activated at the same time prior to movement (Wattanaprakornkul et al., 2011). Considering that this study used similar methodology to the current study, in the choice of electrodes, standardisation of electrode placement, low, medium and high load dynamic exercises and an automated method of determining initial activation timing, the results suggest that supraspinatus is likely to be more vital in the initiation of shoulder flexion than abduction.

The similar initial activation timing of supraspinatus and middle deltoid prior to movement in this current study could indicate that supraspinatus is being recruited to produce shoulder abduction torque. Force studies showing that supraspinatus has a favourable moment arm to produce abduction torque would support this interpretation for the functional role of supraspinatus during the initial stages of shoulder abduction (Ackland et al., 2008; Otis et al., 1994; Poppen and Walker, 1978). However, its similar initial activation time as infraspinatus could also suggest that it may have a functional role as part of the rotator cuff to stabilise the glenohumeral joint during abduction and to therefore, increase the efficiency of the deltoid in producing abduction torque. Force studies indicate that during abduction the rotator cuff activates in response to the concurrent contraction of the deltoid, providing stability, by opposing the superior translatory forces produced by deltoid on the humerus (Sharkey and Marder, 1995). Infraspinatus achieves this by providing a medial and inferior force on the humeral head (Inman et al., 1996; Poppen and Walker, 1978; Sharkey and Marder, 1995), while supraspinatus exerts a medial compressive force (Poppen and Walker, 1978) keeping the humeral head in the centre of the glenoid fossa. The other rotator cuff muscle examined, subscapularis, although considered to have a similar role as infraspinatus during abduction (Inman et al., 1996; Sharkey and Marder, 1995) was shown to have an initial activation later than supraspinatus and infraspinatus. One explanation for this may be that the rotator cuff muscles that perform shoulder external rotation (supraspinatus and infraspinatus) were recruited earlier than subscapularis (a shoulder internal rotator) because the abduction manoeuvres examined in this study were performed with the thumb pointing outward from the anatomical position, causing the shoulder to be in a position of relative external rotation.

Supraspinatus also activated at the same time prior to movement as all axioscapular muscles tested (upper trapezius, lower trapezius and serratus anterior). The activity of these muscles may be contributing to scapular upward rotation. However, as scapular movement below 30° abduction has been shown to be variable and small in range (Inman et al., 1996; Poppen and Walker, 1976) it is more likely that these muscles are being recruited to stabilize the scapula. The rotator cuff and middle deltoid muscles, pulling from their scapular attachments during the initiation of abduction, require the scapula to be appropriately positioned in order to perform their essential mover and/or stabiliser roles at the glenohumeral joint. If the axioscapular muscles fail to contract then these scapulohumeral muscles could potentially move the scapula rather than providing optimal glenohumeral joint stability and movement torque (Reinold et al., 2009).

In conclusion, the present study clearly indicates that supraspinatus, middle deltoid, infraspinatus, upper trapezius, lower trapezius and serratus anterior activate at the same time prior to movement into abduction in the coronal, scapular and scapular +30° planes and at varying loads. The results of this study support the prescription of exercises in the initial stages of abduction as an exercise to target many shoulder muscles including supraspinatus. Additionally, the normative data base that has been established in this study will provide means of comparison for pathological studies to identify potential anomalies in initial timing of muscle activation that may be present in shoulder pathology. Anatomy textbooks need to reflect the fact that shoulder abduction is not initiated by supraspinatus alone but by a group of shoulder muscles in a complex, co-ordinated manner.

Funding

No funding was obtained for this study.

Conflict of interest

None declared.

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