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# Regional activation of anterior and posterior supraspinatus differs by plane of elevation, hand load and elevation angle

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ABSTRACT

The supraspinatus is one of the muscles of the rotator cuff, and growing research on fibre type composition and mechanical advantages in specific postures suggest this muscle may have distinct anterior and posterior regions. Activation differences between these regions may identify important functional differences. This research quantified muscular activation of these regions throughout a range of motion with differing hand loads. Forty participants completed paced humeral elevations in 7 planes of elevation (0/15/30/40/60/75/90°) using 3 hand loads (unloaded arm/20%/40% maximal elevation strength). Indwelling electromyography collected muscle activity of the anterior and posterior supraspinatus. Hand load and elevation angle interacted to affect activity of the anterior supraspinatus in most planes of elevation - by up to 41 %MVC ($p < 0.01$), but in few planes for the posterior region. Plane of elevation influenced anterior and posterior region activation by up to 17 %MVC and 13 %MVC, respectively ($p < 0.01$). Increasing hand loads increased activation in both regions ($p < 0.01$), but more so for the anterior region. These differences may indicate differences in function between the two regions. The sustained activation in the smaller posterior supraspinatus may indicate this region as primarily a glenohumeral stabilizer, while the larger anterior region acts to achieve glenohumeral motion.

## 1. Introduction

The supraspinatus is one of the four muscular elements of the rotator cuff and the most common site of initial rotator cuff pathology. Each rotator cuff muscle originates from the scapula and inserts into the humerus; they collectively act to maintain glenohumeral stability while contributing to humeral movement. The supraspinatus assists in abduction and external rotation of the shoulder (Malanga et al., 1996; Reinold et al., 2004), and is the component most associated with tendinopathies (Jobe and Moynes, 1982). The prevalence of partial- or full-thickness tears increases markedly after 40 years of age: research using 683 volunteers found 16.9% of asymptomatic volunteers had a rotator cuff tear, with prevalence rising from 6.7% from volunteers in their 30 s to 45.8% of volunteers in their 60 s (Wani et al., 2016). The shoulder represents the second most common site for allowed lost time claims behind the low back in 2015, with most shoulder claims relating to overexertion (WSIB, 2015).

Rotator cuff pathologies typically reduce upper extremity function, and often manifest as increased pain or decreased joint range of motion. Patients commonly present to clinicians due to perceived loss of shoulder comfort and function (van der Windt et al., 1995), and specific pathologies. Partial- and full thickness rotator cuff tears are the most common clinical shoulder presentations, and result in decreases in range of motion and strength for 30–50% and 40–60% of patients, respectively (Largacha et al., 2006). These changes can interfere with self-care ability and functional independence, particularly in older adults, decreasing quality of life (Harryman II et al., 1991; Lin, Weintraub, & Aragaki, 2008). Certain occupations are associated with damage to the rotator cuff, including nursing, grocery clerking, warehousing, carpentry and painting (Luopajarvi et al., 1979).

The supraspinatus has a complex morphology that influences mechanical function. It consists of anterior and posterior regions, attaching to different sections of the supraspinatus tendon (Roh et al., 2000; Vahlensieck et al., 1994). These regions have differing distributions of fibre types, with the middle portion of the anterior region having a higher proportion of Type I fibers than the posterior region (Kim et al., 2013). Musculotendinous architechture is an important determinant of muscle function (Lieber and Fridén, 2001). Cadaveric investigations have identified distinct regions of the supraspinatus with different mechanical functions depending on posture (Gates et al., 2010). However, as this work used cadaveric shoulders, it did not examine how these morphological differences influenced muscular activation patterns and potential consequent events.

Differences in activation patterns within the supraspinatus are

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minimally described, but crucial to injury pathogenesis. Previous research detailed differences in activation between the anterior and posterior regions as ratios in static arm postures of 30, 60 and 90° of humeral elevation in the scapular plane, and with a single hand load (Kim et al., 2016). To the author's knowledge, this is the only existing research to examine activation of the supraspinatus as separate regions during any humeral motion. Understanding of the interplay between the anterior and posterior regions is still in its infancy; development of normative posture-activation relationships will delineate the unexplored influence of postural differences and hand loads on concomitant anterior and posterior supraspinatus activations. Rotator cuff pathologies often affect the supraspinatus in initial stages, and often are paired with posterior region atrophy (Karas et al., 2011; Kim et al., 2013, 2010). While research examining supraspinatus across a range of postures and tasks has been examined previously, quantification of the relative activations of both regions can help determine scenarios that increase activation and may increase future injury risk. This study quantified activation patterns of the anterior and posterior regions of the supraspinatus through different humeral ranges of motion and hand loads. Specific hypotheses were that regional activations would depend on both abduction angle and hand load, and that main effects of plane of elevation and hand load would be present in both supraspinatus regions.

## 2. Methods

This study employed electromyography (EMG) and motion capture on human participants. University-aged, right hand dominant individuals participated, and data collection occurred in one two-hour session. Post-collection processing and analysis quantified differences between the two supraspinatus regions and activation patterns through humeral motion.

### *2.1. Participants*

Forty right-handed participants [20 M – 25.0 ± 3.4 yrs, 1.78 ± 0.07 m, 88.2 ± 13.2 kg; 20F – 23.6 ± 3.9 yrs, 1.71 ± 0.07 m, 72.4 ± 12.1 kg] were recruited from a convenience sample. Exclusion criteria included self-reported upper limb or low back pain in the past 12 months, or allergies to rubbing alcohol and skin adhesives. This study was reviewed and received clearance through the institutional Office of Research Ethics.

### *2.2. Electromyography*

EMG was collected from the supraspinatus using indwelling methods. Hypodermic needles, each containing two sterilized fine wire electrodes with barbed ends (Motion Lab Systems, Inc., Louisiana, USA) was inserted into the muscle belly of the anterior and posterior regions of the supraspinatus using previously published instructions (Kim et al., 2016). Each needle was inserted to the appropriate depth by visually confirming location using ultrasound imaging. All EMG signals were sampled at 3000 Hz using a wireless telemetered system (Noraxon Telemyo 2400 T G2, Noraxon, Arizona, USA). Raw signals were band-pass filtered from 10 to 1000 Hz and differentially amplified with a common-mode rejection ratio > 100 dB and an input impedance of 100 MΩ. Analog signals were converted to digital using a 16 bit A/D card with a ± 3.5 V range.

### *2.3. Motion capture*

Three-dimensional motion was captured using thirteen VICON MX20 optoelectronic infrared cameras. These cameras tracked the position of reflective markers secured to the skin over anatomical landmarks. Three rigid clusters placed on the humerus, acromion and torso and 7 individual markers placed on the epicondyles of the right elbow, right acromion, suprasternal notch, xiphoid process, the 7th cervical and 8th thoracic vertebrae were tracked. Captured kinematic data was recorded with the VICON Nexus 1.8.5 software (VICON Motion Systems, Oxford, UK), and was sampled at 50 Hz. Following marker placement, calibration trials ensued. While the participant stood in the anatomical position, a stylus was used to palpate and record the position of the root of the scapular spine, the inferior angle, and the acromion angle (Grewal et al., 2017). The relationship between the acromion cluster and these points allowed digital recreation of scapular orientation in post-processing.

### *2.4. Protocol*

The protocol for each participant for each experimental session involved the sequential application of electromyography equipment, collection of maximal voluntary exertions, a 5-min rest period, application of reflective markers for motion capture, then collection of experimental trials. Participants completed multiple repetitions of a maximal voluntary isometric exertion test under manual resistance. This test was designed to elicit maximal activation from the supraspinatus, and was derived from the literature (Criswell, 2011). This exertion was completed three times to improve reliability of the results (Fischer et al., 2010). Exertions had a minimum of two minutes rest interposed (Chaffin, 1975). The highest post-processing electrical activity from these trials served as the reference to normalize subsequent electromyographic data for each respective supraspinatus region (Winter, 1991). These trials were filtered and processed using the same methods as experimental trials.

Following maximal voluntary isometric exertions, participants completed two maximal elevation force trials to establish individual hand force strength capacity by which to scale experimental hand loads. Participants sat in a backless chair identical to the one used in experimental trials, and raised their arm to 90° humeral elevation in the frontal plane, with their thumb facing the ceiling. A hand dynamometer was placed on the wrist, and participants pushed upwards. Each trial lasted five seconds, and the maximal force from these two trials was used to determine the load of two bottles filled with lead shot representing 20% and 40% of this maximal strength value.

Each experimental trial involved dynamic upper limb motion. Seven planes of elevation (0°/15°/30°/40°/60°/75°/90°) and three hand loads (unloaded/20%/40% of maximal elevation strength) were varied and each was completed twice, resulting in 42 testing scenarios. The shoulder elevation plane originated from the approximate glenohumeral joint centre. The 0° plane is humeral abduction, while the 90° plane coincides with humeral flexion. Elevation planes were measured externally with a goniometer over the glenohumeral joint, coincident with the vertical y-axis of the thorax coordinate system (Wu et al., 2005). Humeral elevation angle was calculated with kinematic data after collection. Each participant had two seconds to raise their humerus to at least 165° of elevation starting from the anatomical position, then two seconds to return their arm to the starting position. A metronome at 1 Hz was used to assist in this motion. A thin metal rail was placed just posterior to the current plane of elevation to act as a guide throughout the trial (Fig. 1D). Two researchers (one seated behind the participant, one seated to the right of the participant) visually examined the motion of the participant to ensure participants stayed in the desired plane of elevation. If the participants did not maintain the desired plane of elevation, the trial was recollected. Participants were seated on a backless chair and experimental trials will be completed in a randomized order.

### *2.5. Data analysis*

EMG was analysed with respect to amplitude. All signals were processed using custom MATLAB code (Matlab R2016, Mathworks Inc., Natick, MA). A high pass 4th order Butterworth filter with a cut-off