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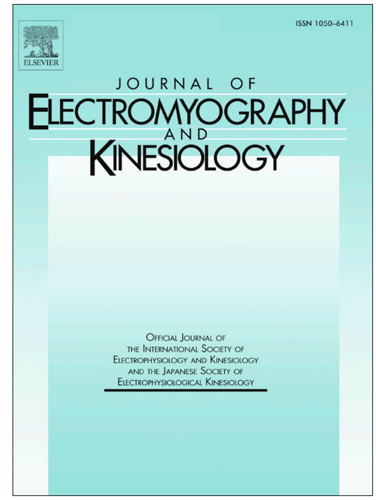

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Alan C. Cudlip, Clark R. Dickerson

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REGIONAL ACTIVATION OF ANTERIOR AND POSTERIOR SUPRASPINATUS DIFFERS BY PLANE OF ELEVATION, HAND LOAD AND ELEVATION ANGLE

Alan C. Cudlip, Clark R. Dickerson

Department of Kinesiology, University of Waterloo, Waterloo, Canada

Address: 200 University Avenue W, Waterloo, ON, CANADA

N2L 3G1

Alan C Cudlip – accudlip@gmail.com

Clark R Dickerson – cdickers@uwaterloo.ca

Corresponding Author: cdickers@uwaterloo.ca

Phone: 519-888-4567 x37844; Fax 519-746-6776

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CONFLICT OF INTEREST

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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.

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 30s to 45.8% of volunteers in their 60s (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 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 90º 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.

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.

Participants

Forty right-handed participants [20M – 25.0 ± 3.4 yrs, 1.78 ± 0.07m, 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.

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 10-1000 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.

[INSERT FIGURE 1 APPROXIMATELY HERE]

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 50Hz. 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.

Protocol

The protocol for each participant for each experimental session involved the sequential application of electromyography equipment, collection of maximal voluntary exertions, a 5-

minute 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 (0º/15º/30º/40º/60º/75º/90º) 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 0º plane is humeral abduction, while the 90º 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 165º of elevation starting from the anatomical position, then two seconds to return their arm to the starting position. A metronome at 1Hz 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 (Figure 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.

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 frequency of 30Hz was applied to all signals in order to mitigate potential heart rate contamination (Drake and Callaghan, 2006). The signals were full-wave rectified and low-pass single pass filtered using a 2nd order Butterworth filter with a 4 Hz cutoff frequency; this cutoff is commonly used for the low frequency motion of upper extremity musculature (Winter, 2009). Each trial was normalized to muscle specific maximum voluntary exertion data that were processed identically.

Kinematic analysis consisted of data filtering, marker reconstruction and local joint coordinate system construction, followed by conversion of marker data to joint center data and calculation of joint rotation sequences. All raw kinematic data was low pass filtered with a cutoff frequency of 6 Hz (Winter, 2009), and segment length and orthogonal coordinate systems were constructed using ISB guidelines (Wu et al., 2005). Static calibration trials for the scapula using the stylus were used to reconstruct the scapular coordinate system. Thoracohumeral rotations were calculated using ISB standards. These rotations used a Y-X-Y' sequence, representing plane of elevation, elevation angle, and humeral axial rotation (Wu et al., 2005).

Statistical Analysis

Statistical analysis focused on assessing the activations of the anterior and posterior regions by posture. Normalized activation for both regions at seven thoracohumeral elevation angles (5/30/60/90/120/135/165°) in both the ascending and descending phases of motion were extracted. A repeated measures ANOVA with 3 independent factors (plane of elevation, hand load, elevation angle) and each 2-way interaction examined muscle activity differences. Analyses were divided by phase of motion (ascending, descending). All statistical analyses were completed with JMP 14.0 software (SAS Institute, North Carolina, USA), with statistical significance considered at $\alpha = 0.05$. Tukey HSD post-hoc analysis were conducted to identify levels of difference when warranted.

RESULTS

Activation levels for both supraspinatus regions were influenced variously by hand load, plane of elevation and elevation angle. An interaction between hand load and elevation angle was observed in anterior supraspinatus during the ascending phase of movement in all planes but 30° (p=0.01-0.02), and in the descending phase of movement in the 0°, 15° and 40° planes of elevation ($p<0.01$ for each). The largest observed difference between elevation angles and loads occurred between the unloaded raise at 5° of elevation (4.7 +/- 3.2 %MVC) and the 40% load at 90° of elevation in the 0° plane of elevation (46.1 +/- 6.1 %MVC), generating a 41.4 %MVC change (Figure 2). Interactions between hand load and abduction angle only affected posterior supraspinatus activation in the ascending phase in the 30° and 40° planes of elevation (p=0.01-0.02), and did not affect activation in any plane during the descending phase of movement. These activations included increases of 34.6 and 35.9 %MVC respectively with increased hand load, with activation peaking around 90° of elevation. While there was no statistically significant interaction between plane of elevation and hand load, both the anterior and posterior regions had near-significant differences in the descending phase of motion (p = 0.05-0.08), with higher activation in more sagittal planes and higher hand loads. There was no interaction effect on activation between plane of elevation and elevation angle (p=0.13-0.85).

Main effects of load, plane of elevation and abduction angle affected both regions of supraspinatus. These main effects altered activation at all planes of elevation in both phases of movement (p<0.01). Increasing hand loads resulted in increased muscle activation in both regions in all planes of elevation. In the anterior region, differences in loads altered muscle activation by up to 17 %MVC in the 0° plane during elevation, and by as little as 7.0 %MVC in the 90° plane during depression. The posterior region saw similar differences by hand load across planes, with the largest activation in the 0° plane during elevation (13.7 %MVC) and the smallest in the 75° plane (5.9 %MVC). Typically, differences between lighter loads and heavier loads were greater in planes closer to the sagittal plane. Plane of elevation affected both regions of supraspinatus (p<0.01), with more sagittal planes increasing supraspinatus activation (Figure 3). Differences in activation between planes increased when the load increased. Increasing humeral abduction increased muscular activation across all planes of elevation (p<0.01).

Elevation angles of 60° and below always generated the lowest muscle activation, with elevation angles above 60° producing increased activation, but activations at 90° and above were not always statistically different from one another. The largest range in activation was in the elevation phase of motion, of 30.7 %MVC in the anterior and 25.2 %MVC in the posterior region (30° plane of elevation, 5°-135° ; 0° plane of elevation, 5° -165°, respectively) (Table 1).

[INSERT FIGURE 2 APPROXIMATELY HERE]

[INSERT FIGURE 3 APPROXIMATELY HERE]

[INSERT FIGURE 4 APPROXIMATELY HERE]

[INSERT TABLE 1 APPROXIMATELY HERE]

DISCUSSION

The focus of this research was to examine regional activation changes in the anterior and posterior supraspinatus during arm elevations while altering the plane of elevation and hand loads. Several activation differences within both supraspinatus regions were associated with various planes of elevation and hand loads. Interactions between hand load and elevation angle existed, as well as main effects of hand load, plane of elevation and abduction angle on both anterior and posterior supraspinatus activation. These activation differences occurred across the range of motion, but influenced the anterior and posterior regions differently.

The anterior and posterior supraspinatus had activation differences throughout the range of motion that were likely due to functional differences between these regions. Mounting evidence suggests that the anterior and posterior regions of supraspinatus have functional distinctions (Hermenegildo et al., 2014; Kim et al., 2017, 2013; Roh et al., 2000). The interaction between load and humeral abduction angle was far more evident in the anterior region, occurring in almost all planes of elevation in the ascending phase of movement and nearly half of the examined planes of elevation in the descending phase of motion. Greater loads and humeral elevation angles also increased anterior supraspinatus activation, peaking at 90° of thoracohumeral elevation. Peaks occurred above 90° in the posterior supraspinatus (Figure 2). Additionally, differences related to hand loads were far more pronounced in the anterior region. Above 90° elevation in both externally loaded scenarios, activation in the posterior region was within 1 %MVC, despite doubling hand load. The anterior region of the supraspinatus is larger and produces 71% of the total muscle force of the supraspinatus by PCSA (Gates et al., 2010). It attaches to a thicker, more tubular tendon that represents 47% of the total supraspinatus tendon cross-sectional area (Gates et al., 2010), and also has a larger flexor moment arm than the posterior supraspinatus, particularly between 18-54° of flexion (Ackland et al., 2008). The smaller moment arm and force capability of the posterior region may indicate its primary role as a glenohumeral stabilizer, while the anterior region primarily assists in generating motion. Sustained loading of the posterior region to generate stability may lead to chronic injury and atrophy of the supraspinatus, as ~50% of cases observed with large retracted supraspinatus tendon tears had no distinguishable posterior region (Karas et al., 2011; Kim et al., 2013, 2010). It is undetermined whether atrophy of the posterior region leads to rotator cuff pathology or that the inverse exists; however is important to understand that these items are indelibly linked. Further research is required to further elucidate this relationship between the posterior region of the supraspinatus and injury pathology.

Plane of elevation affected supraspinatus capability for both regions of supraspinatus. Activation for both regions decreased as the plane of elevation moved from the abduction plane to the flexion plane, despite identical hand loads. Similar decreases in activation have been observed in the anterior supraspinatus using fine wire EMG previously (Alenabi et al., 2016). The posterior supraspinatus activation similarly decreased across planes, but this difference in normalized activation was relatively smaller. Main effects of plane of elevation altered anterior region activation by up to 11.2 %MVC, but the posterior region by only up to 6.7 %MVC. The posterior region has been thought to quickly adjust tension on the rotator cuff, preventing buckling with dynamic motion (Hermenegildo et al., 2014; Kim et al., 2013). This sustained activation across planes supports the idea that the posterior region acts as a stabilizer, while the anterior region is responsible for assisting in shoulder motion.

There were some limitations inherent to this study. The participants were university-aged individuals with no self-reported history of upper extremity injury or pathology which limits the applicability of these results to an injured population. Additionally, only the supraspinatus was examined. Expanded interpretation of the results outside the context of the interplay between other muscles of the shoulder complex should be approached cautiously.

This study provides advanced knowledge surrounding activation of the supraspinatus, and further confirms that this muscle has distinct subregions with different functions related to upper extremity use. It represents the most comprehensive evaluation of the supraspinatus regions over a large set of planes of elevation and hand loads throughout the range of humeral elevation, providing a more complete description of supraspinatus activation. Further, this research provides novel insights into the posterior region of supraspinatus, which is commonly associated with rotator cuff pathology. Further insights into the previously neglected complexity of the supraspinatus can improve understanding of rotator cuff pathology initiation and prevention. These findings can be leveraged to better simulate in vivo conditions more accurately, as well as determining biomechanically relevant loading scenarios for in vitro tissue testing aimed at tendinopathy pathogenesis.

CONFLICT OF INTEREST

None of the authors have any conflict of interest related to this work.

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This project was partially funded through an NSERC Discovery Grant held by corresponding author, 311895-2011. Equipment used in the grant was funded through combined support from the Canada Foundation for Innovation and the Ontario Research Fund. Dr. Clark Dickerson is also supported as an NSERC Canada Research Chair in Shoulder Mechanics.

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Table 1. Statistical results for normalized activation (%MVE) of anterior and posterior supraspinatus by plane of elevation and elevation angle. Significant differences by plane are denoted by letters; values not sharing a letter are significantly different.

Phase of Movement	Muscle Region	Plane of Elevation	Elevation Angle (°) 5	30	60	90	120	135	165
Ascending	Anterior	0	6.7 (C)	21.1 (B)	30.9 (A)	34.7 (A)	34.8 (A)	32.9 (A)	32.4 (A)
		15	4.3 (C)	15.9 (B)	26.6 (A)	29.8 (A)	32.0 (A)	28.5 (A)	27.7 (A)
		30	3.6 (C)	13.8 (B-C)	24.9 (A-B)	28.2 (A-B)	29.1 (A-B)	34.3 (A)	33.7 (A)
		40	3.9 (C)	12.2 (B)	23.8 (A)	28.0 (A)	28.7 (A)	27.7 (A)	26.9 (A)
		60	4.5 (D)	10.4 (C)	20.8 (B)	27.5 (A)	27.1 (A)	24.3 (A-B)	24.0 (A-B)
		75	3.3 (D)	8.3 (C)	18.4 (B)	25.1 (A)	24.5 (A)	21.9 (A-B)	21.4 (A-B)
		90	3.6 (C)	7.5 (C)	15.1 (B)	20.8 (A)	23.3 (A)	21.6 (A)	21.3 (A)
	Posterior	0	7.6 (C)	20.1 (B)	28.6 (A)	30.1 (A)	32.8 (A)	32.5 (A)	32.8 (A)
		15	7.0 (C)	18.9 (B)	29.3 (A)	31.4 (A)	29.7 (A)	29.2 (A)	27.7 (A)
		30	5.6 (C)	16.6 (B)	26.8 (A)	28.3 (A)	27.8 (A)	27.7 (A)	27.1 (A)
		40	6.4 (C)	14.2 (B)	24.8 (A)	27.6 (A)	27.7 (A)	25.6 (A)	24.7 (A)
		60	7.4 (C)	13.5 (B)	25.1 (A)	27.6 (A)	25.2 (A)	25.0 (A)	24.6 (A)
		75	4.8 (C)	11.1 (B)	22.6 (A)	26.5 (A)	23.8 (A)	22.2 (A)	22.0 (A)
		90	7.1 (C)	14.3 (B)	23.3 (A)	26.2 (A)	24.7 (A)	24.1 (A)	23.6 (A)

Descending	Anterior	0	11.1 (D)	13.0 (D)	21.2 (C)	23.6 (B-C)	27.0 (A-B)	31.4 (A)	31.5 (A)
		15	9.8 (C)	13.1 (C)	18.6 (B)	18.8 (B)	24.8 (A)	26.4 (A)	26.6 (A)
		30	10.5 (B)	12.5 (B)	17.8 (A-B)	19.1 (A-B)	22.1 (A-B)	32.5 (A)	32.6 (A)
		40	9.2 (E)	12.7 (D-E)	17.0 (C-D)	19.4 (B-C)	21.9 (A-B)	26.0 (A)	26.1 (A)
		60	8.9 (D)	11.1 (D)	15.7 (C)	17.5 (C)	19.2 (B-C)	23.3 (A-B)	23.6 (A)
		75	9.2 (D)	10.7 (C-D)	14.6 (B-C)	17.2 (A-B)	18.1 (A-B)	20.3 (A)	20.5 (A)
		90	8.0 (D)	9.1 (D)	13.2 (C)	14.9 (B-C)	17.8 (A-B)	20.5 (A)	20.6 (A)
	Posterior	0	16.2 (C)	21.5 (B-C)	22.9 (B)	24.7 (A-B)	26.4 (A-B)	29.6 (A)	30.3 (A)
		15	15.1 (C)	18.0 (C)	23.1 (B)	22.7 (B)	23.3 (A-B)	26.7 (A-B)	27.2 (A)
		30	15.5 (D)	18.3 (C-D)	21.0 (B-C)	22.2 (B)	23.0 (A-B)	26.1 (A)	26.4 (A)
		40	14.9 (B)	17.5 (B)	21.5 (A)	22.6 (A)	23.0 (A)	23.8 (A)	24.3 (A)
		60	16.1 (C)	17.4 (B-C)	20.6 (A-B)	22.5 (A)	20.7 (A-B)	23.4 (A)	24.2 (A)
		75	15.2 (C)	17.1 (B-C)	20.9 (A)	19.3 (A-B)	20.4 (A)	21.7 (A)	21.8 (A)
		90	15.4 (C)	17.2 (B-C)	19.3 (A-C)	21.9 (A)	20.8 (A-B)	22.7 (A)	22.7 (A)

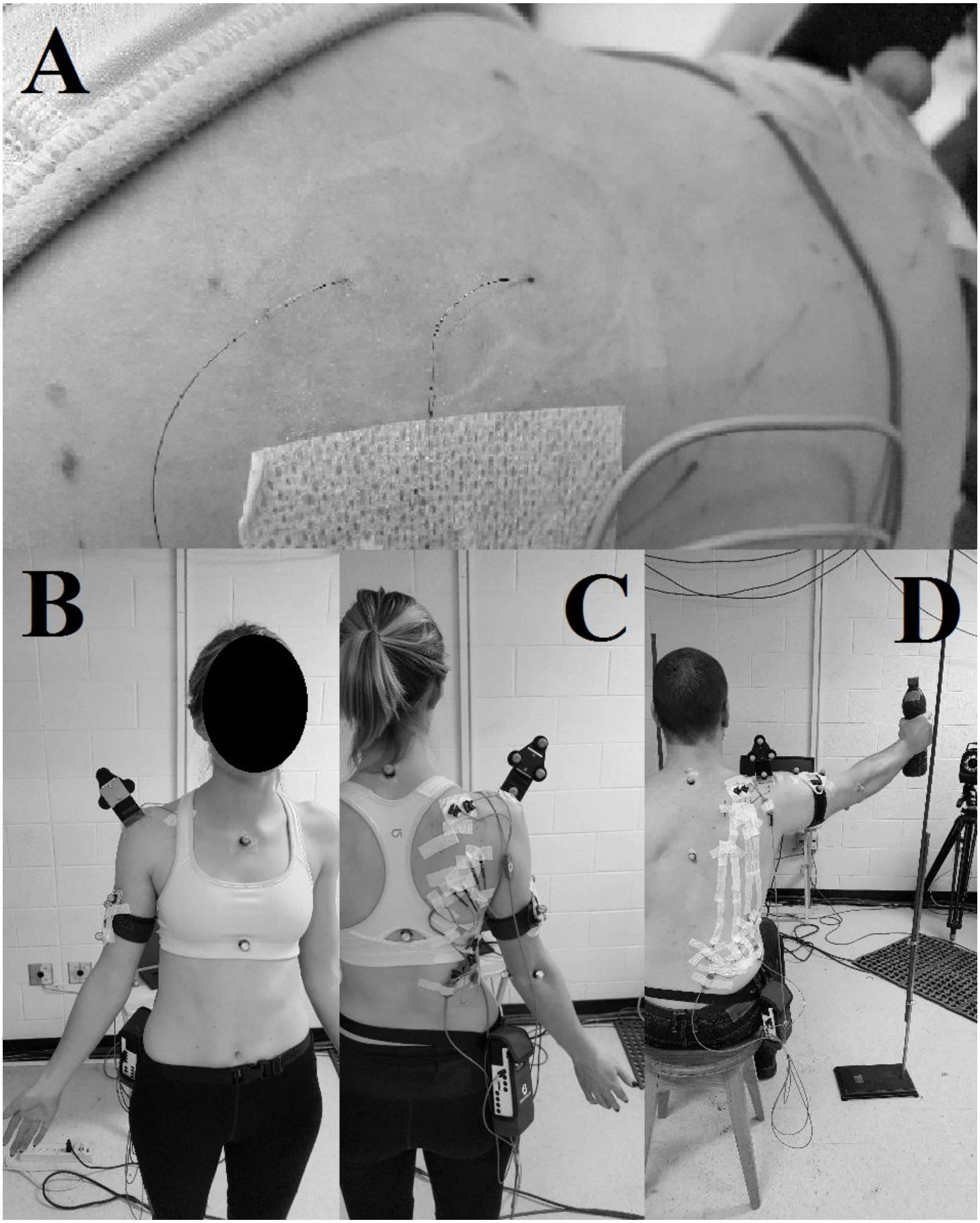
List of Figures

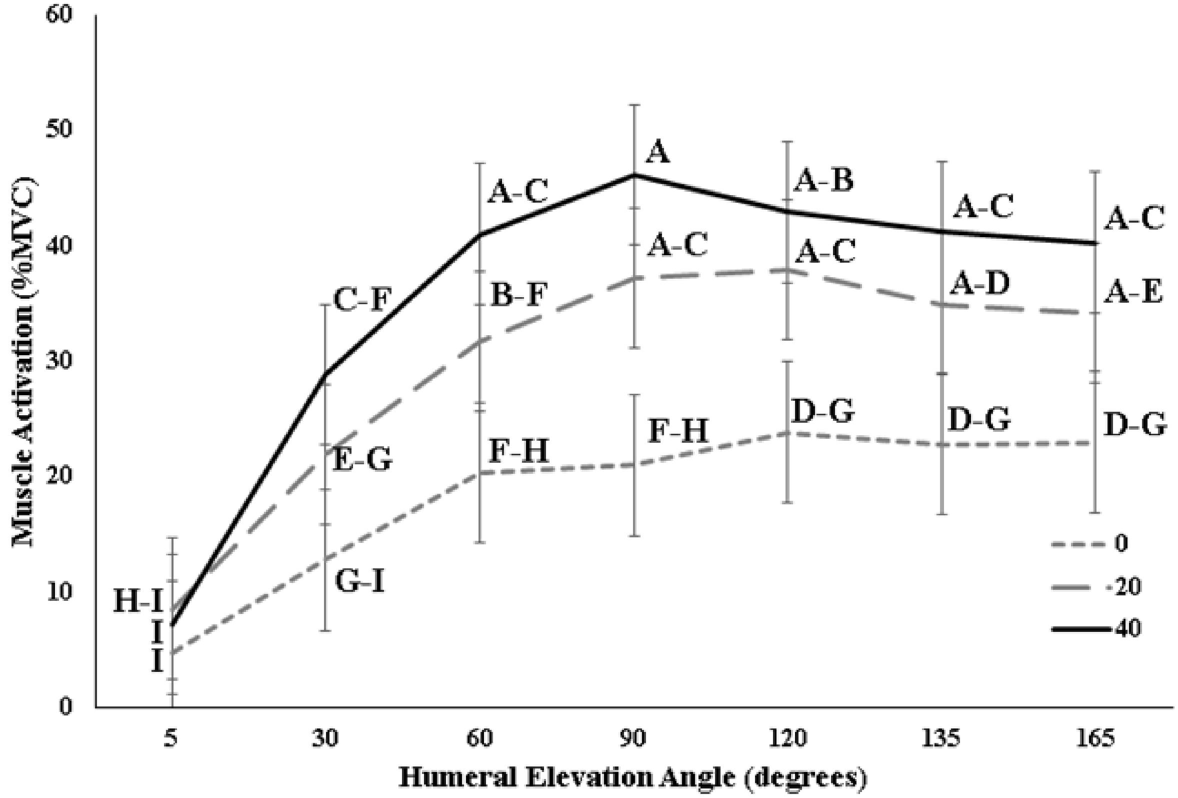
Figure 1. Experimental set-up. Two indwelling electrodes were placed into the anterior and posterior supraspinatus with ultrasound guidance (A). Motion capture markers were placed over bony landmarks of the torso and right upper extremity (B,C). Participants completed maximal arm elevations at a fixed cadence (2 seconds to maximal elevation, 2 seconds to return to zero elevation) in different planes of elevation with differing hand loads. A guide rail was used to indicate plane of elevation for participants during experimental trials. Shown here is the ascending phase of an exertion in the 40° plane of elevation with the 20% hand load (D).

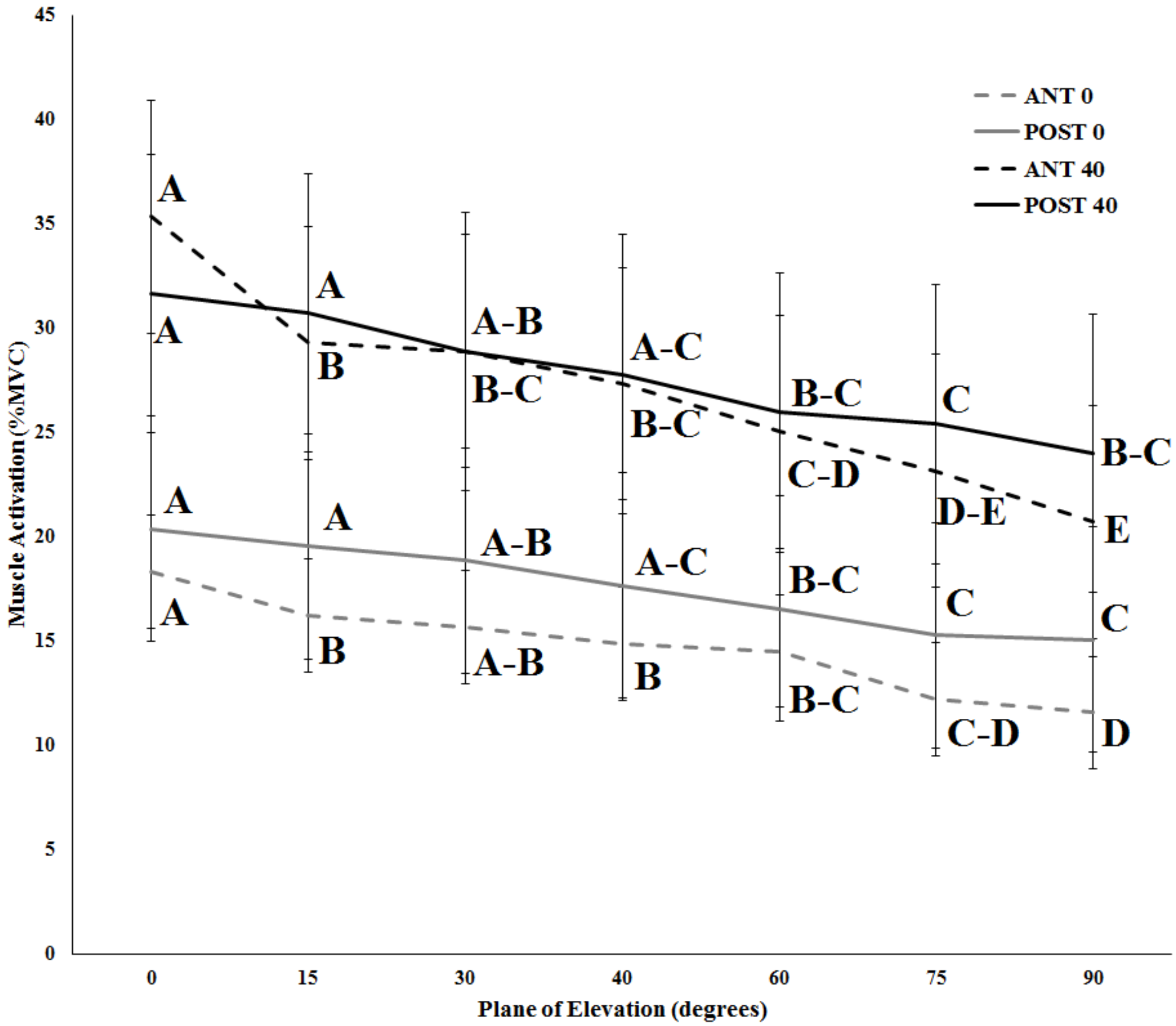
Figure 2. An interaction between load (unloaded/20%/40% of maximal elevation strength) and thoracohumeral elevation angle affected muscle activation. Shown above is the anterior supraspinatus in the 0° plane of elevation during the ascending phase of movement. Post-hoc differences are denoted by letters; points not sharing a letter are significantly different.

Figure 3. Normalized muscle activation of anterior (ANT) and posterior (POST) supraspinatus across loads (unloaded/40% maximal elevation strength). Plane of elevation affected muscle activation, with more sagittal planes increasing activation in ascending motion. Post-hoc differences within muscle and load are denoted by letters; points within a load not sharing a letter are significantly different.

Figure 4. Normalized muscle activation of anterior (ANT) and posterior (POST) supraspinatus across loads (unloaded/40% maximal elevation strength). Plane of elevation affected muscle activation, with more sagittal planes increasing activation in descending motion. Post-hoc differences for each muscle-load combination are denoted by letters; points within a load not sharing a letter are significantly different.


A
B
C
D


60
50
40
30
20
10
0
Muscle Activation (%MVC)
5
30
60
90
120
135
165
Humeral Elevation Angle (degrees)
A
A-C
A-B
A-C
A-C
C-F
A-C
A-C
A-D
A-E
B-F
E-G
F-H
F-H
D-G
D-G
D-G
H-I
I
I
G-I
0
-20
40


45
40
35
30
25
20
15
10
5
0
Muscle Activation (%MVC)
0
15
30
40
60
75
90
Plane of Elevation (degrees)
ANT 0
POST 0
ANT 40
POST 40
A
A
A
A
A
B
A
B
A-B
B-C
A-B
A-B
A-C
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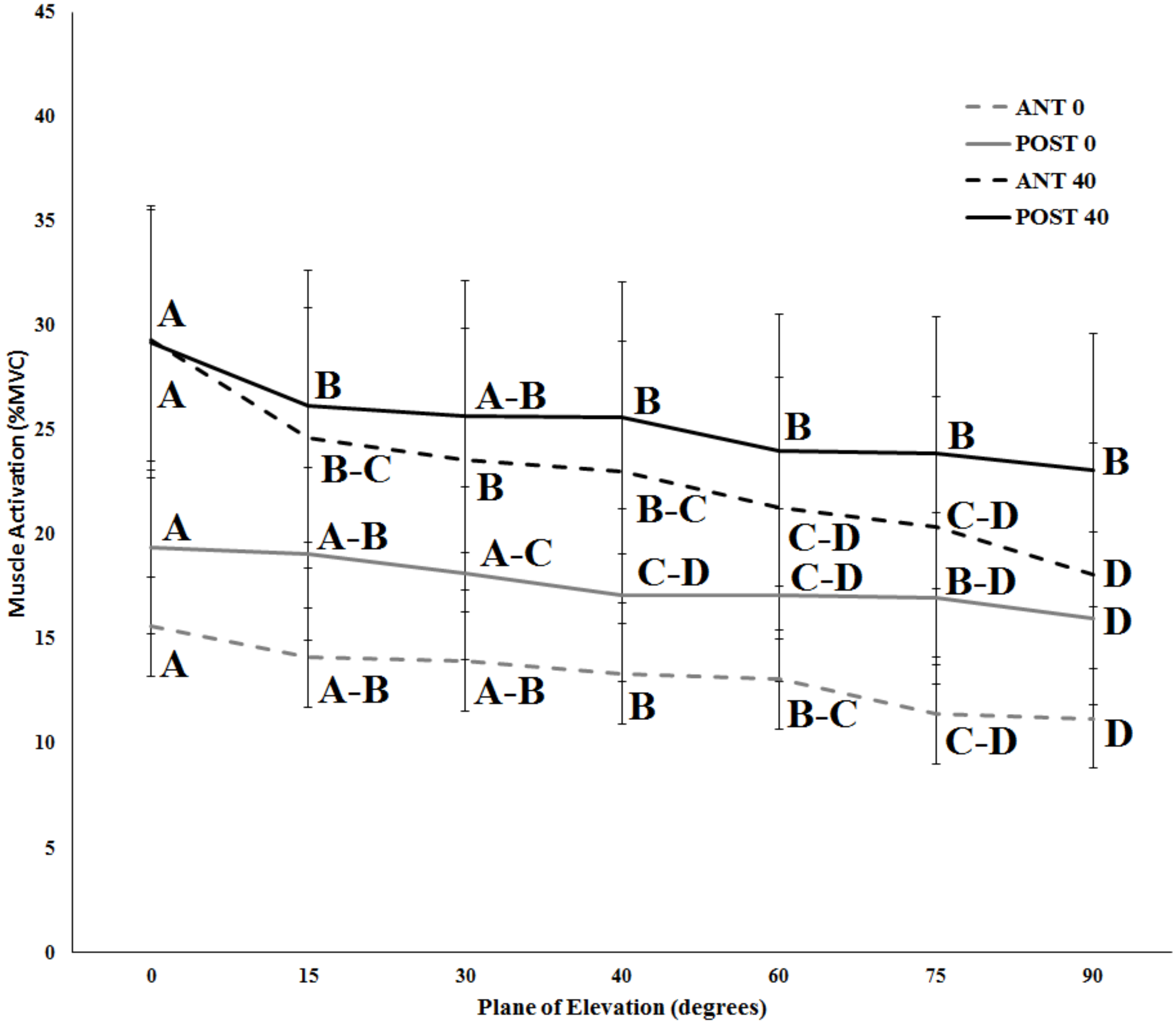
E
C
D


ANT 0
POST 0
ANT 40
POST 40
Muscle Activation (%MVC)
Plane of Elevation (degrees)
0
5
10
15
20
25
30
35
40
45
0
15
30
40
60
75
90
A
A
A
A
B
B-C
A-B
A-B
A-B
B
A-C
A-B
B
B-C
C-D
B
B
C-D
C-D
B-C
B
C-D
B-D
C-D
B
D
D
D

Author Biographies:

Alan Cudlip (MSc) is a doctoral student in the Digital Industrial Ergonomics and Shoulder Evaluation Laboratory at the University of Waterloo in Waterloo, ON, Canada. He received his BSc in Kinesiology from the University of Waterloo in 2012, and his MSc in Kinesiology in 2014. His research interests involve human performance, tissue damage mechanisms, rotator cuff disease, proactive work design specific to the shoulder and upper extremity.

Clark Dickerson (PhD) is a Professor of Kinesiology and Canada Research Chair of Shoulder Mechanics at the University of Waterloo, where he has been since 2005. His research focuses on human musculoskeletal biomechanics, particularly of the shoulder. He earned his BSME at Alfred University, his MS in bioengineering from Clemson University, and his PhD in biomedical engineering from the University of Michigan. His current research interests include the development and experimental evaluation of computational shoulder models, digital ergonomics, age- and disease-related shoulder disorder prevention, assessment, and mitigation, in vitro tissue mechanical characterization, and comparative shoulder mechanics. He is the current past-president of the Canadian Society for Biomechanics and a member of the Board of the International Shoulder Group.