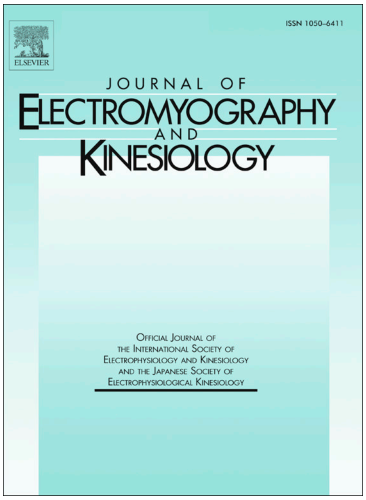

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Arm Posture Influences on Regional Supraspinatus and Infraspinatus Activation in Isometric Arm Elevation Efforts

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Arm Posture Influences on Regional Supraspinatus and Infraspinatus Activation in Isometric Arm Elevation Efforts

Abstract:

This study aimed to evaluate the effect of arm posture on activation of the anterior and posterior regions of supraspinatus and the superior and middle regions of infraspinatus during resisted isometric arm elevations.

Thirty-one healthy participants performed eighteen isometric resistance exertions against a robotic arm in three elevation planes (flexion, scaption, abduction) and three elevation angles (30°, 90°, 150°) in maximal and sub-maximal resistance conditions. EMG data were obtained using fine wire electrodes. The mean activation of each region and the activation ratios were compared across postures using ANOVAs.

Supraspinatus anterior was significantly more active during abduction and scaption, and in higher elevation angles, while the posterior region showed similar activation levels across postures. Infraspinatus regions were more active during flexion with more relative activation of the infraspinatus superior at 90° flexion.

The results suggest that regional activation of supraspinatus and infraspinatus should be considered for assessment and rehabilitation purposes. In any clinical condition that less stress on the supraspinatus anterior is desired, isometric training in flexion or in lower elevation levels may strengthen the supraspinatus posterior while causing lower stress in the anterior region. Beside external rotation exertions, resisted flexion tests may be useful for evaluation of infraspinatus regions.

1 INTRODUCTION

Isometric arm efforts require synchronous agonist action of shoulder stabilizing muscles and prime movers. Biomechanical studies suggest that the rotator cuff muscles stabilize the glenohumeral joint and assist prime movers such as deltoids (Sharkey and Marder, 1995). Several electromyographic (EMG) studies have quantified rotator cuff muscle activation during different shoulder exercises and identified postures that place these muscles under higher demand, exertion or stress. Reed et al., (2016) reported that the supraspinatus and infraspinatus muscles had similar levels of activation in different planes of elevation. Alpert et al., (2000) have quantified the activation of rotator cuff muscles across different elevation arcs in the scapular plane and observed that the peak activation of supraspinatus and infraspinatus muscles occurred in the 30°- 90° arc. Although valuable data have been derived from these observations, few studies have considered a combined effect of elevation planes and elevation angles on activation of the rotator cuff muscles in maximal or submaximal load conditions. Quantifying muscle activation levels across shoulder range of motion can help identifying the best assessment or rehabilitation methods for rotator cuff muscles. Further, motor control studies have highlighted significant differences in upper limb muscle coordination strategies in submaximal tasks between males and females (Côté, 2012). However, potential sex differences in the context of elevation posture for muscle activation have not been studied.

In addition, recent anatomical studies showed that there are neuro-anatomically distinct regions within the supraspinatus (Kim et al., 2007) and infraspinatus muscles (Fabrizio and Clemente, 2014). Kim et al., (2017) contrasted the anterior and posterior regions of the supraspinatus muscle by presenting EMG data from each region as a single activation ratio (supraspinatus anterior/posterior). This ratio was a convenient representation of the relative activation of different regions across arm postures. They suggested that the posterior region contributed more in positions that involved arm elevation and external rotation. However, the effects of plane and angle of elevation on the activation ratio were not a focus of that study. To date, no EMG study has compared the activation of different regions of infraspinatus in different postures. As a glenohumeral joint stabilizer, the infraspinatus muscle is active in arm external rotation, abduction and flexion (Ludewig et al., 2009). Activation of infraspinatus is critical for functional arm elevation and even more so when there is supraspinatus dysfunction (Otis et al., 1994). Defining the regional activation of supraspinatus and infraspinatus, first in healthy individuals, will enhance clinicians' ability to distinguish normal and pathological muscle function. Such information can also provide guidelines for appropriate adjustment in rotator cuff assessment methods as well as rehabilitation plans for each particular muscle region.

The aim of this study was to quantify the activation of the anterior and posterior regions of the supraspinatus and the superior and middle regions of the infraspinatus during isometric arm elevations in different arm postures with maximal and sub-maximal load conditions, to explore: 1) if elevation angle, plane and their interaction influenced the activation of each interested muscle region, and the regional activation ratios, and 2) if these activation patterns were sex-dependent. We hypothesized that the activation of the regions within supraspinatus and infraspinatus and the regional activation ratios would be distinctly affected by the arm posture, and that no sex effect existed.

2 METHODS

2.1 Participants

Thirty-one right-handed, healthy individuals participated in the study. This included 16 females (age=21.8 ± 1.6 years, height =160.5 ± 8.6 cm and weight = 58.2 ± 7.7 kg) and 15 males (age=23.2 ± 3.4years, height =176 ± 8.9 cm and weight = 77.4 ± 12.9 kg). Exclusion criteria included a history of injury or surgery in the right upper limb or any neuromuscular disease. All participants provided informed consent and the study was approved by the university office of research ethics.

2.2 Instrumentation

Muscle activation of the anterior and posterior regions of supraspinatus were measured with indwelling electrodes as described by Kim et al., (2017), using either 30 mm (27 gauge) or 50 mm (25 gauge) manufactured needles (Chalgren Enterprises, Inc, CA, USA) or a 75 mm (23 gauge) custom made needle (Quinke Point, Kimberly Clark Spinal QP Needle). Intramuscular electrodes were also placed into the superior and middle regions of infraspinatus muscle as explained by Alenabi et al. (2018). The needle size was chosen based on each participant's subdermal fat tissue and muscle thickness. A reference electrode was placed on the right clavicle. The data were collected using a Noraxon telemyo 2400 G2 system (Noraxon, Arizona, USA) with 3000 Hz sampling rate. 10-1000 Hz band-pass filter was applied to raw EMG signals and the signals were differentially amplified (common-mode rejection ratio >100 dB at 60 Hz, input impedance 100 MΩ) and converted to a digital signal (16-bit A/D card, maximum +/-10V range).

2.3 Test Protocol

Participants performed 15 maximal voluntary isometric contractions (MVICs), outlined by Alenabi et al., (2018), in a randomized order (Table 1). Each exertion was held for 5 seconds with at least 1-2 min rest between tests. A total of 9 test postures were examined in this study, at three elevation angles (30°, 60°, 90°) in each of the frontal, scapular and sagittal plane of motion (abduction, scaption, flexion respectively). Participants completed one maximum voluntary force (MVF) and one submaximal (50% MVF) exertion in each posture (Figure 1). They were asked to stand with feet slightly apart until feel balanced. The position of the robotic arm was adjusted based on participants' individual anthropometrics (height, arm length) for the various test postures. Participants' right upper limb posture, relative to their trunk, was verified by an examiner using a goniometer. The wrist was maintained in a neutral posture during all exertions, facilitated by a fully moveable handle that was locked into position and attached to the force transducer mounted on the robot arm. All isometric exertions were performed against a tri-axial force transducer ("force cube"; MC3A, AMTI, MA, USA) attached to the robot arm. The orientation of the force transducer ensured participants' exerted force perpendicular to the midpoint of the transducer. Force feedback was monitored in real time using a custom LabView program (National Instruments, Austin Texas).

Figure 1

Table 1

For maximal efforts, participants were instructed to gradually increase force until reaching their maximum, holding for 3s and then gradually return to rest. Force data were sampled at 1500 Hz (1000x gain) and converted to a digital signal (12 bit A/D card). Particiants' force signals were displayed on screen to assist them monitoring their maximal force. Participants also performed a submaximal effort in each test posture. The force signals were calibrated from volts to %MVF and force feedback displayed on screen by two lines which indicated 50%max ± 10 N.

Participants were asked to keep their submaximal force between these two lines for 5 sec. The tests were performed in a randomized order, separated by a minimum of 1-2 minutes of rest between trials to minimize muscle fatigue accumulation.

2.4 EMG Signal Processing

The raw EMG data were digitally bandpass filtered (10-1000 Hz), full wave rectified and then a 2nd order Butterworth low pass filter (fc = 2 Hz) was applied. For each muscle region, the maximum value across all the MVIC and MVF postures was extracted to represent the global muscle-specific maximum voluntary excitation (gMVE). The peak activation of each muscle during the middle 3s of the isometric elevation trials was subsequently normalized to the gMVE to obtain a normalized value (%MVE). In addition, the following activation ratios were calculated: Supraspinatus Anterior/ Supraspinatus Posterior (SA/SP), Infraspinatus Superior/Supraspinatus Posterior (IS/SP), Infraspinatus Superior /Infraspinatus Middle (IS/IM).

2.5 Statistical Analyses

Muscle activations (% MVE) for each posture were inputted into separate general linear models (i.e. one per muscle x load) using SPSS software version 21 (IBM Corp). The normal distribution of variables was ensured by Shipiro-Wilk test. One between-subject factor (sex) and two within-subject factors (angle and plane) were set corresponding to each posture. For ratios, three within-subject factors were tested: 1) angle, 2) plane and 3) load. Significance was set at $p<0.05$ and Tukey HSD comparisons with a significance of $p<0.05$ were used to test significant main effects and interactions.

3 RESULTS

The effect of plane and/or angle was significant for all of muscle regions of this study except the supraspinatus posterior in both load conditions (Table 2). The effect of sex was only significant for middle infraspinatus. Table 3 and 4 present the averaged activation values for each muscle region across postures and indicate where the significant differences exist. The changes in regional activation ratios was only significant for the infraspinatus regions in flexion exertions (Table 5)

*** Insert Table 2 here ***

*** Insert Table 3 here ***

*** Insert Table 4 here ***

3.1 Supraspinatus

The activation of the supraspinatus anterior (SA) was influenced by the angle and plane of exertion at 50% MVF (Angle: $p<0.001$, Plane: $p=0.026$). The average SA muscle activity was significantly greater at 90° and 150° as compared to 30° of elevation ($p < 0.05$) (Table 3). Despite a main effect of plane, no significant differences existed between planes after post hoc testing. At 100% MVF there was a significant interaction of angle and plane on SA muscle activation ($p<0.001$) (Figure 2). At 30° of elevation, mean activation in the flexion plane (40.3%MVE) was significantly lower than in the abduction (53.2%MVE) and scaption (48.6%MVE) planes ($p < 0.05$). Within the scaption and flexion planes, mean activation was significantly higher at 90° and 150° as compared to 30° of elevation, ($p < 0.05$) and in the abduction plane, mean activation was significantly higher at 90°(68.6%MVE) as compared to 30° (53.2%MVE) ($p < 0.05$).

There were no main effects or interactions of angle, plane or sex on the activation of the supraspinatus posterior (SP) muscle. At 50% MVF, the mean activation of SP across angles and planes ranged from 38.4-44.8% MVE whereas this range increased at 100% MVF to 60.3-65.8% MVE across angles and planes (Table 3 and 4).

*** Insert Fig 2 here***

3.2 Infraspinatus

The interaction of angle and plane influenced the activation of the infraspinatus superior (IS) at both 50% (p=0 .014) and 100% (p=0.003) MVF (Figure 3). At both load conditions (50% and 100% MVF), and in 90° of elevation, mean activation of IS was lower in the abduction plane (19.6%MVE and 42.5%MVE) than the flexion (33.2%MVE and 60.3%MVE) or scaption (30.9%MVE and 53.7%MVE) planes. Activation within the flexion plane was significantly higher in 90° compared to 30°. There were no significant differences in activation across elevation angles in the abduction or scaption planes.

Insert Fig 3 here

At 50% MVF, there was a main effect of plane on the average activation of the infraspinatus middle (IM) (p<0.001). Across angles, IM activation was significantly lower in the abduction plane (24.4%MVE), as compared to the scaption (31.6%MVE) and flexion planes (31.9%MVE) ($p < 0.05$) (Table 3). At 100% MVF, there was a main effect of plane (p<0.001), angle (p=0.002) and sex (p=0.013) on IM activation. Across angles, IM activation was significantly greater in the flexion plane, as compared to the abduction plane ($p < 0.05$) (Table 4). The main effects of angle and sex are influenced by one another, evident by the significant angle x sex interaction (p=0.017) (Figure 4). Across planes, at 90° and 150° of elevation, males had significantly higher IM activation as compared to females (p < 0.05).

Insert Fig 4 here

3.3 Ratios

The SA/SP ratio had main effects of angle (p=0.003) and load (p=0.042) as well as an interaction between load and plane (p=0.042). However, post hoc testing of these factors revealed no significant differences in the means. Nonetheless, there was a trend of higher SA/SP ratio at higher elevation (90° and 150° vs. 30°) angles across planes (Table 5).

There were main effects of plane (p<0.001) and load (p=0.009) on the IS/IM ratio. The mean IS/IM ratio was significantly greater in the flexion plane, as compared to the abduction plane (Table 4; p<0.05). Post hoc testing of the main effects of angle and plane revealed no significant differences between these groups. However, a significant interaction between angle and plane on the IS/IM ratio was observed (p<0.01) and this ratio was significantly greater in 90° of flexion as compared to the other planes (p<0.05).

There were no significant main effects or interactions on the IS/SP ratio.

Insert Table 5 here

4 DISCUSSION

This study showed that apart from the posterior region of supraspinatus, activation patterns of all the other muscle regions were affected by plane and/or angle of arm elevation either as an isolated effect or as part of an interaction effect. The effect of sex was only significant for the activation of the middle region of the infraspinatus where males had 16%MVE and 32%MVE higher activation in 90° and 150° of maximally resisted arm elevation than females respectively. The relative activations of the supraspinatus muscle regions (SA/SP ratio), and the muscle regions in the two sides of spine of scapula (IS/SP) were not affected by arm posture. While, the relative activation of the infraspinatus regions (IS/IM ratio) was higher in 90º of flexion compared to abduction and scaption. The results of this study can help clinicians to have better understanding of the regional activation patterns and more test choices for assessment or rehabilitation of each individual supraspinatus or infraspinatus muscle region.

4.1 Supraspinatus

Only the activation of the supraspinatus anterior was influenced by the arm posture during isometric arm elevation. This may imply that the posterior region has mostly a stabilizing role in isometric arm exertions performed in any plane or angle of elevation. Anatomical studies reveal that the posterior region contains a higher percentage of fast twitch fibers (Kim et al., 2013) attached to a broader tendon than the anterior region (Kim et al., 2007; Roh et al., 2000). These characteristics may allow the posterior region to quickly adjust its tension over the broader aspect of the supraspinatus tendon during arm elevation. The anterior region of supraspinatus accounts for over 75% of muscle volume (Roh et al., 2000), and has a slower maximum shortening velocity based on higher percentages of type I fiber in the middle part of this region (Kim et al., 2013). However, the anterior portion of supraspinatus tendon has smaller cross sectional area (Gates et al., 2010) and includes 40% of the insertion site (Itoi et al., 1995). Given a high muscle volume in comparison to that of the tendon, the anterior supraspinatus tendon may be more vulnerable to mechanical stress. A computational model of supraspinatus tendon that could predict tear propagation suggested that the anterior tears in supraspinatus tendon required significantly lower load to propagate compared to the posterior tears (Miller et al., 2017). Thus, it is important to consider how much stress may be applied to the anterior region in different arm postures. The posterior region may play an important role in balancing the applied force over the supraspinatus tendon as a whole.

Unlike the observation of Kim et al. (2017), in the current study SA/SP activation ratio increased with arm elevation, although the differences were not statistically significant. This disagreement may be attributed to different methodology of these two studies as the statistical observations in the former study focused on the median values, whereas the present data set summarized by the mean. The current study showed that in general the supraspinatus anterior had more relative activation in 90° of arm elevation than 30° with both maximal and submaximal resistance. The activation of this region did not dramatically increase in 150° of elevation and was even slightly lower in 150° (60.9%MVE) than 90º (68.6%MVE) of maximally resisted abduction. This observation is in agreement with Alpert et al. (2000) who reported a consistently lower activation between 90º-150º of elevation than 0-90° arcs.

With respect to the plane of elevation, abduction and scaption could generate higher activation in the supraspinatus anterior than flexion. For submaximal load condition, our results are similar to Reed et al., (2016) who compared shoulder muscle activations during dynamic full arm elevations, and detected a main effect of plane for the supraspinatus anterior in abduction, scaption and scaption+30 planes, but the differences were not confirmed in post hoc analysis. Alenabi et al., (2016) performed a similar study but on a group of patients with rotator cuff tear and reported that the mean activation of the supraspinatus anterior was almost doubled during arm scaption and abduction compared to flexion. Different study designs limit direct comparison of the current study with the above mentioned study. However, our data indicates a significant postural effect on maximal activation of the supraspinatus anterior. This confirms that maximally resisted abduction or scaption at 90° (full can posture) - as previously suggested (Kelly et al., 1996; Rowlands et al., 1995) can better elicit the supraspinatus anterior. Nevertheless, in any condition that less stress on the supraspinatus anterior is desired (such as post supraspinatus tendon repair), isometric training in flexion or in lower degrees of elevation can potentially strengthen the supraspinatus posterior while causing lower stress in the anterior region.

This study did not find any effect of sex on the activation of supraspinatus muscle during isometric tasks. Female participants had higher variability in supraspinatus activation during repetitive motion (Fedorowich et al., 2013) and higher relative supraspinatus activation during painting activities than their male counterparts (Meyland et al., 2014). There is no comparative supraspinatus data for isometric tasks in the literature.

4.2 Infraspinatus

The activation of both regions of the infraspinatus muscle in isometric arm elevation trials was affected by arm posture. The infraspinatus is usually regarded as an external rotator, however, its role in arm elevation is also well documented (Hermenegildo et al., 2013; Kato et al., 2012; Otis et al., 1994). The current study is in agreement with Wattanaprakornkul et al., (2011) suggesting that both regions of the infraspinatus muscle become highly activated during arm flexion (Table 2). However, the superior region showed more relative activation in keeping arm at 90° flexion with bigger IS/IM ratio (0.77) than the other arm postures. Therefore, beside external rotation maneuvers, resisted flexion at 90º may potentially be a useful assessment test for evaluation of the infraspinatus superior and middle and resistance exercises at 90° flexion may particularly be helpful in strengthening of the superior region.

The relative activation of the infraspinatus superior to the supraspinatus posterior (IS/SP) did not change across postures. The infraspinatus superior has a smaller cross sectional area and larger pennation angles than the middle region (Hermenegildo et al., 2013), and its tendon overlaps the posterior portion of the supraspinatus tendon at the insertion site (Minagawa et al., 1998). These anatomical observations suggest that the infraspinatus superior may aid the supraspinatus posterior to stabilize the tendon during arm elevation. Investigation on the temporal activations of IS and SP during dynamic tasks can better reveal the synergic activation of these two regions. Nonetheless, it is well documented that the atrophy or fat infiltration of the infraspinatus muscle is linked to the manifestation of the supraspinatus tear (Cheung et al., 2011) and the repair outcomes (Gladstone et al., 2007). Future studies should evaluate which region of the infraspinatus plays a more critical role in this respect.

The middle region of infraspinatus was the only region with sex-dependent activation. This may reflect the previous findings that suggested gender differences existed for shoulder neuromuscular control (Vafadar et al., 2015) and scapular kinematics (Nakayama et al., 2018). This may also be attributed to greater muscle mass of the middle region in male participants, as this region forms almost 50% of total muscle volume (Hermenegildo et al., 2013). Future anatomical studies are needed to confirm this explanation.

4.3 Limitations

One limitation of this study was the technical difficulties in collecting EMG from the inferior region of infraspinatus as explained by Alenabi et al. (2018). Future studies on the infraspinatus muscle may consider the activation of this region as well. Second, while three elevation angles and three planes of elevation were evaluated, the activation patterns would likely differ in other isometric elevation postures. Also, our findings are on isometric exertions, and it is not clear whether these results apply to dynamic motions that include these postures.

5 CONCLUSION

This study suggests that apart from the supraspinatus posterior, the activation of the other regions within the supraspinatus and infraspinatus muscles during isometric elevation exertions are posture dependent. Maximally resisted arm elevation at 90° of abduction or scaption could highly recruit the supraspinatus anterior while the posterior region was similarly recruited across the studied postures. Therefore, isometric training in flexion or in lower elevation angles can potentially strengthen the supraspinatus posterior while causing lower stress in the anterior region. The superior and middle regions of the infraspinatus were more active during arm flexion and the infraspinatus superior showed a larger relative activation, in resisted arm flexion at 90°. These observations suggest that in addition to external rotation exertions, resisted arm flexion efforts may be useful for assessment or strengthening of infraspinatus muscle regions. Apart from the activation of the infraspinatus middle, none of the observed activation patterns were sex specific. Further studies are needed to explain the effect of sex on regional activation of infraspinatus. These findings will enhance clinicians understanding of the activation patterns of different regions within these two rotator cuff muscles; information that is pertinent for appropriate selection of the postures used in manual testing or resistance training of the particular muscle region.

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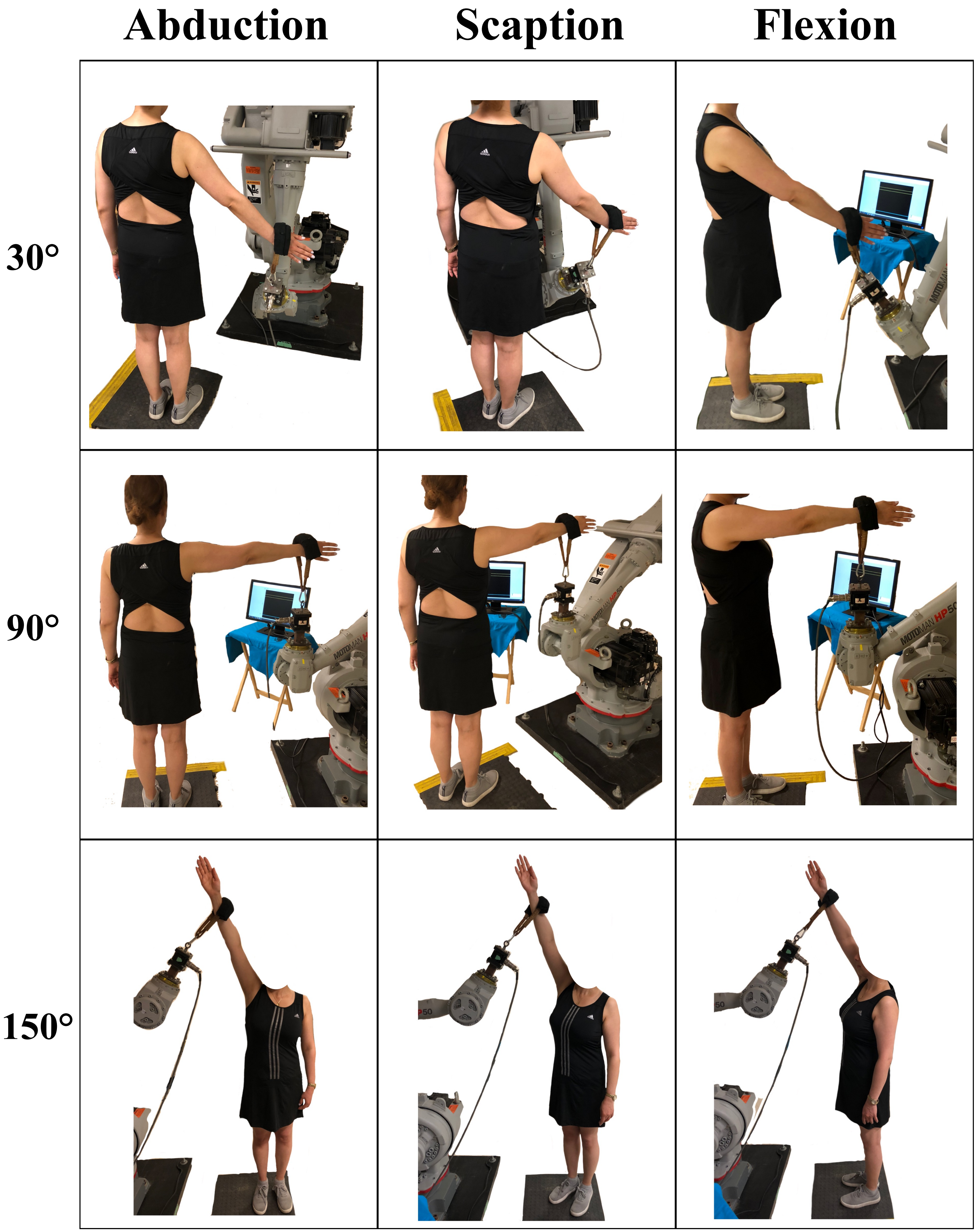
Figure Legends:

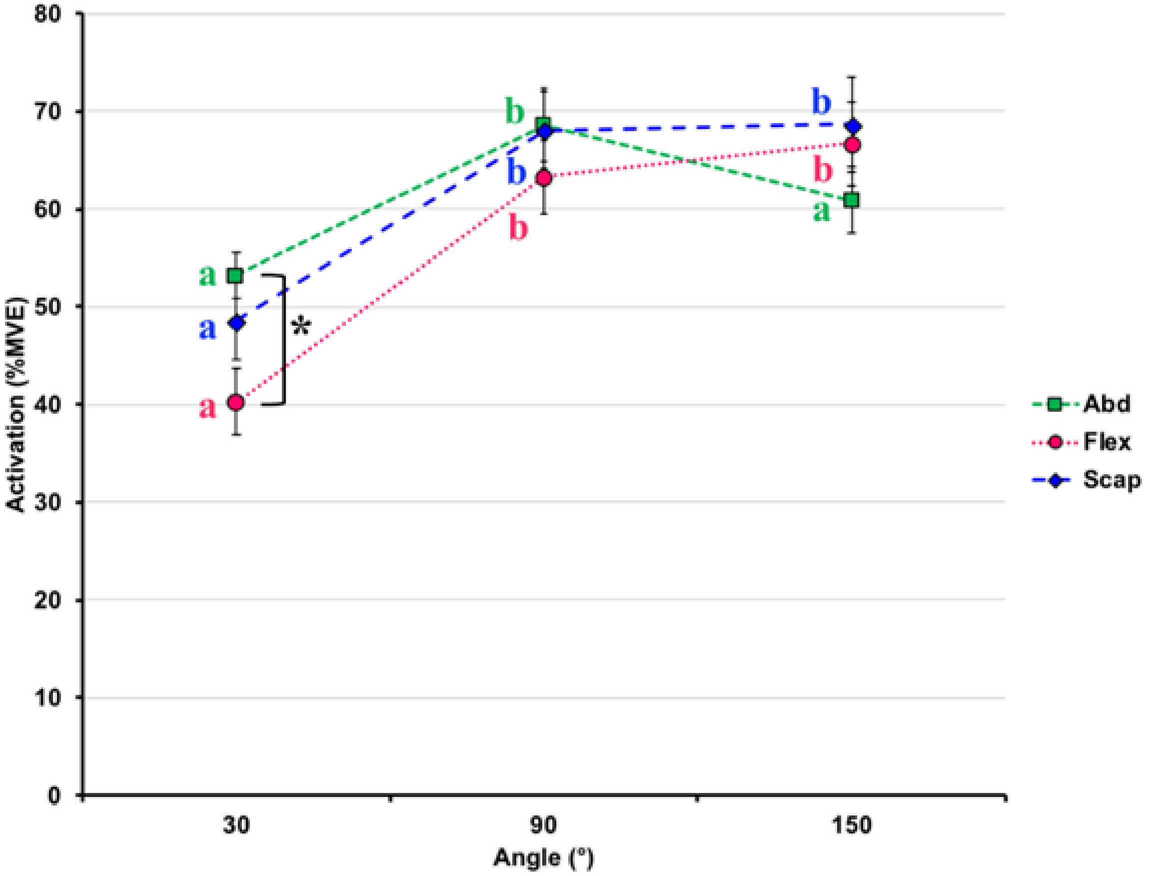
Figure 1: Experiment design with robotic arm. The participants exerted force perpendicular to the midpoint of the force transducer

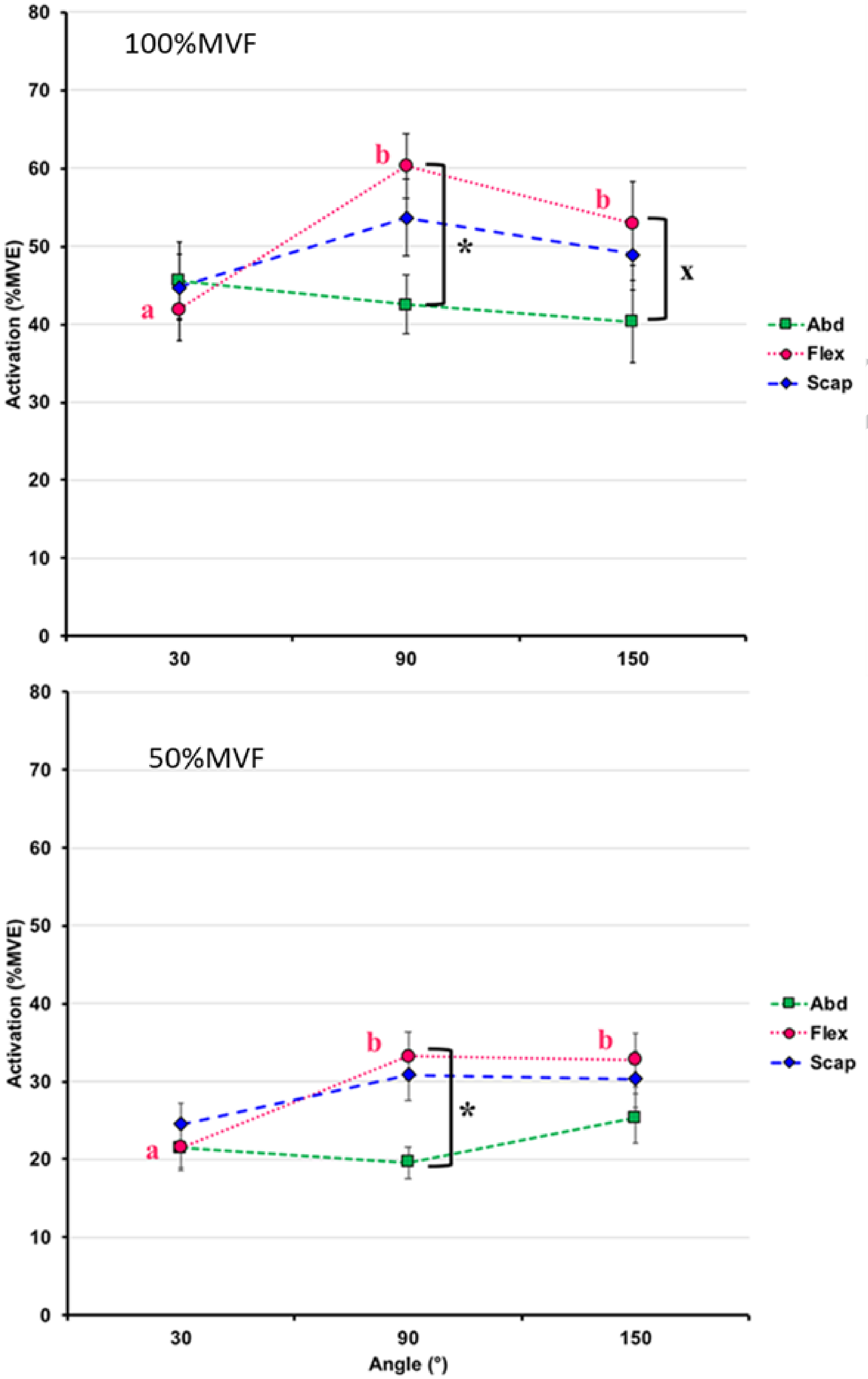
Figure2: The mean activation of supraspinatus anterior (%MVE ± SE) at 100% MVF for each angle and plane combination. Significant differences in means are shown with letters, color coded to each plane. Points with different letters represent a significant difference between the two means. An asterisk shows the significant difference between planes at 30°, indicating higher activation in the abduction and scaption planes as compare to the flexion plane. Abd = Abduction, Scap = scaption, Flex = Flexion

Figure 3: Activation of the infraspinatus superior (%MVE ± SE) at 100% and 50% MVF for each angle and plane combination. Significant differences in means are shown with letters, color coded to each plane. Points with different letters represent a significant difference between the two means. The significant difference between planes at 90° and 150° of elevation is indicated with an asterisk and an x respectively. Abd = Abduction, Scap = scaption, Flex = Flexion

Figure 4: Mean infraspinatus middle activation (%MVE ± SE) at 100% MVF for each angle, separated by participants' sex. Significant differences in means between sexes are indicated with an asterisk.


Abduction
Scaption
Flexion
30°
90°
150°


80
70
60
50
40
30
20
10
0
Activation (%MVE)
30
90
150
Angle (°)
a
a
a
*
b
b
b
b
b
a
Abd
Flex
Scap


100%MVF
Activation (%MVE)
0
10
20
30
40
50
60
70
80
30
90
150
a
b
b
*
x
Abd
Flex
Scap
50%MVF
Activation (%MVE)
0
10
20
30
40
50
60
70
80
30
90
150
Angle (°)
a
b
b
*
Abd
Flex
Scap

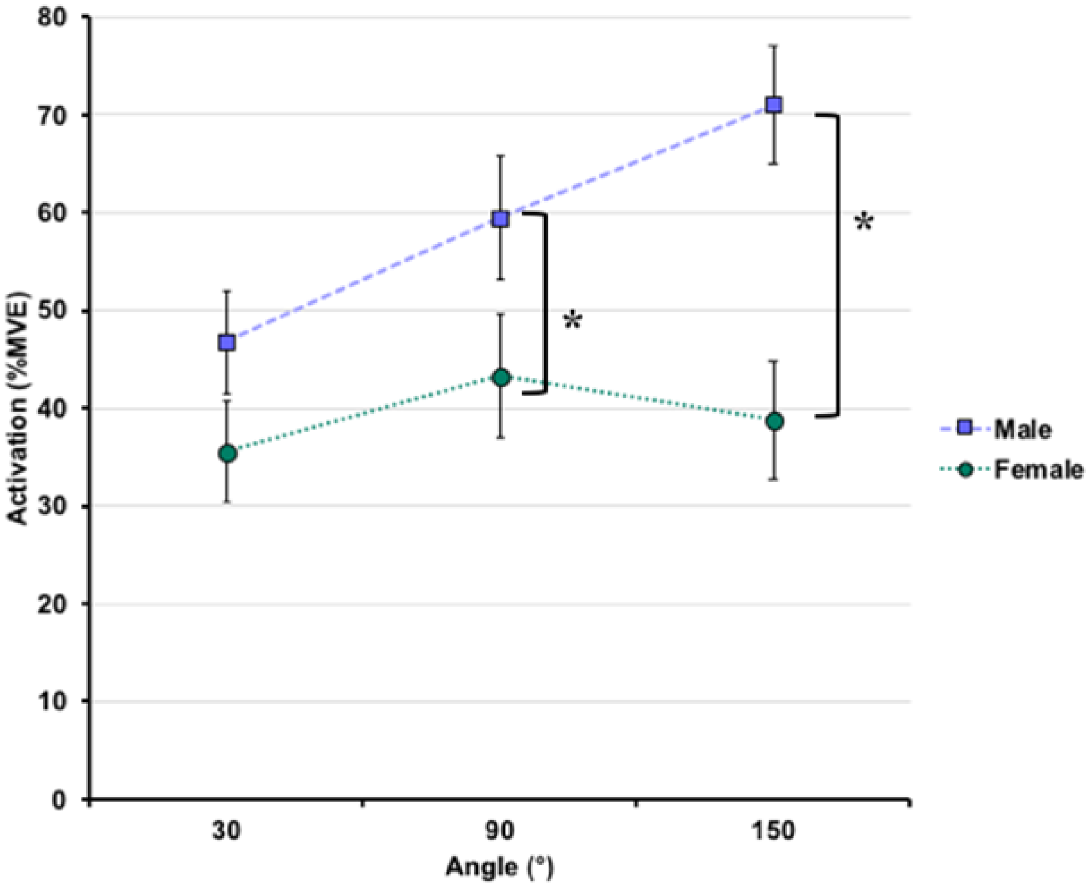

80
70
60
50
40
30
20
10
0
Activation (%MVE)
30
90
150
Angle (°)
*
*
Male
Female

Table 1: MVIC tests: explanation of the test positions*

Test Name	Description
Flexion (90°)	Seated, arm flexion in 90° is resisted
Abduction (90°)	Seated, arm abduction in 90°is resisted
Prone Ext (90°)	Prone lying, arm abducted 90°, externally rotated, palm up, and arm elevation is resisted
Fullcan (60°)	Seated, arm elevated 60° in scapular plane, thumb is up; resistance is applied downward on the arm
Fullcan (90°)	Seated, arm elevated 90° in scapular plane, thumb up; resistance is applied downward on the arm
Emptycan (60°)	Seated, arm elevated 60° in scapular plane, thumb down; resistance is applied downward on the arm
Emptycan (90°)	Seated, arm elevated 90° in scapular plane, thumb down; resistance is applied downward on the arm
Sit ER (0°)	Seated, arm beside the body, elbow flexed 90°, external rotation is resisted
Sit ER (45°)	Seated, arm in 45°abduction, elbow flexed 90°, external rotation is resisted
Sit ER (90°)	Seated, arm in 90°abduction, elbow flexed 90°, external rotation is resisted
Sit ER (110°)	Seated, arm in 90°abduction, elbow flexed 90°, external rotation is resisted
Prone ER (90°)	Prone lying, arm abducted 90°, palm facing the floor; external rotation is resisted

Side ER (0°)	Left side lying, arm close to the body, elbow flexed 90, external rotation is resisted
Side Abduction (10°)	Left side lying, arm abducted 10°, resistance applied downward on the right arm
Side Abduction (45°)	Left side lying, arm abducted 45°, resistance applied downward on the right

ER = external rotation, Ext = extension
**= reported by Alenabi et al. 2018*

Table 2: The significant effect of plane, angle and sex on activation level of supraspinatus and infraspinatus regions ($p < 0.05$). x = significant effect with 50% load; + = significant effect with 100% load

Muscle	**Angle**	**Plane**	**Sex**	**Angle × Plane**	**Angle × Sex**	**Plane × Sex**	**Angle × Plane × Sex**
Supraspinatus Anterior	**x**	**x**	-	+	-	-	-
Supraspinatus Posterior	-	-	-	-	-	-	-
Infraspinatus Superior	-	-	-	**x** +	-	-	-
Infraspinatus Middle	**x**+	**x**+	+	-	+	-	-

Table 3: Mean rotator cuff muscle activation (%MVE) at 50% MVF collapsed across planes and angles. A significant difference between means is shaded in grey and further noted by a letter. The bolded values indicate the means that are significantly higher, the letter "a" indicates a significantly larger mean than that at 30° of elevation. The letter "b" indicates a significantly larger mean than that in the abduction plane.

Muscle	Angle			Plane		
	30°	90°	150°	Abduction	Flexion	Scaption
Supraspinatus Anterior	28 (1.8)	**41.9 (2.3)** [a]	**45.3 (3.2)** [a]	38.9 (2.2)	35.5 (2.3)	40.7 (2.4)
Supraspinatus Posterior	38.4 (2.6)	42.6 (2.9)	44.8 (3.1)	40.5 (2.9)	41.4 (2.5)	43.9 (2.6)
Infraspinatus Superior	22.5 (2.1)	27.9 (2.2)	29.5 (3.2)	22.1 (2.1)	29.2 (2.4)	28.6 (2.5)
Infraspinatus Middle	26.6 (2.9)	28.7 (3)	32.5 (2.7)	24.4 (2.3)	**31.9 (2.9)** [b]	**31.6 (3.1)** [b]

Table 4: Mean rotator cuff muscle activation (%MVE) at 100% MVF collapsed across planes and angles. A significant difference between means is shaded in grey and further noted by a letter. The bolded values indicate the means that are significantly higher, the letter "a" indicates a significantly larger mean than that at 30° of elevation. The letter "b" indicates a significantly larger mean than that in the abduction plane.

Muscle	Angle			Plane		
	30°	90°	150°	Abduction	Flexion	Scaption
Supraspinatus Anterior	47.4 (2.9)	**66.7 (3.3)** [a]	**65.4 (3.9)** [a]	60.9 (2.5)	56.8 (2.9)	61.8 (3.5)
Supraspinatus Posterior	63 (4.7)	65.8 (4.1)	60.3 (3.9)	64.1 (3.9)	61.9 (3.2)	63.1 (3.6)
Infraspinatus Superior	44.1 (4)	52.2 (3.3)	47.4 (4.7)	42.8 (3.8)	51.8 (3.3)	49.2 (3.6)
Infraspinatus Middle	41.2 (3.7)	51.4 (4.5)	54.9 (4.3)	43.9 (3.6)	**52.6 (3.8)** [b]	50.9 (3.8)

Table 5: Mean rotator cuff ratios collapsed across planes, angles and loads. A significant difference between means is shaded in grey and further noted by a letter. The letter “a” indicates a significantly larger mean than that in the abduction plane. supra = supraspinatus, infra = infraspinatus, abd = abduction

Ratio	Angle			Plane			Load (%MVF)	
	30°	90°	150°	Abd	Flexion	Scaption	50	100
Supra Anterior/ Posterior	0.74 (0.06)	0.96 (0.06)	0.96 (0.08)	0.92 (0.06)	0.85 (0.07)	0.89 (0.05)	0.86 (0.05)	0.91 (0.06)
Infra Superior/ Middle	0.64 (0.08)	0.70 (0.07)	0.64 (0.07)	0.57 (0.06)	**0.77 (0.07) a**	0.65 (0.07)	0.63 (0.06)	0.69 (0.07)
Infra Superior/ Supra Posterior	0.76 (0.1)	0.77 (0.06)	0.71 (0.09)	0.71 (0.07)	0.76 (0.08)	0.77 (0.08)	0.76 (0.08)	0.74 (0.07)

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