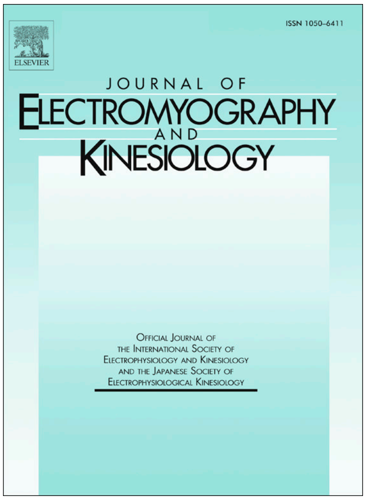

Regional Activation of Supraspinatus and Infraspinatus Sub-regions During Dynamic Tasks Performed with Free Weights

Ronelle Calver, Talia Alenabi, Alan Cudlip, Clark Dickerson, Prosanta Mondal, Soo Y. Kim

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Authors: Ronelle Calver[1], MD, Talia Alenabi[2], MD, PhD, Alan Cudlip[2], MSc, PhD candidate, Clark Dickerson[2], PhD, Prosanta Mondal[3], PhD, Soo Y. Kim[4], PT, PhD

1. McMaster University, Department of Medicine, Physical Medicine and Rehabilitation, Hamilton, Ontario, Canada
2. University of Waterloo, Faculty of Applied Health Sciences, Department of Kinesiology, Digital Industrial Ergonomics and Shoulder Evaluation Laboratory (DIESEL), Waterloo, Ontario, Canada
3. University of Saskatchewan, College of Medicine, Department of Community Health and Epidemiology, Saskatoon, Saskatchewan, Canada
4. University of Saskatchewan, College of Medicine, School of Rehabilitation Science, Saskatoon, Saskatchewan, Canada

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Corresponding Author:
Dr. Soo Y. Kim
soo.kim@usask.ca
(306) 966-8399

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Abstract

Growing evidence supports the existence of distinct anatomical sub-regions within supraspinatus and infraspinatus, but only recently has attention turned to exploring their potential functional differences. Using indwelling fine-wire electromyography, muscle activity was investigated from these sub-regions in 15 participants (mean 34 yr, 170 cm, 71.9 kg) during dynamic external rotation (ER), abduction, flexion, and scaption tasks with and without free weights corresponding to 50% and 75% of the participant's five repetition maximum. Electromyography data were normalized to isometric and isokinetic maximal voluntary contractions and activation ratios for each sub-region compared.

Differences in mean regional activation ratios for supraspinatus and infraspinatus varied by arm posture, but were not influenced by load. Relative activation of posterior supraspinatus was greater during an ER task performed in side lying compared to an ER task performed with 90° of humeral elevation in seated and prone postures. Relative activation of superior infraspinatus was greater during an ER task in prone and side lying postures compared to flexion and scaption. Similar results were found when comparing regional muscle activation ratios for infraspinatus between tasks regardless of normalization method employed. These findings may impact exercise selection in the non-operative management of rotator cuff tears.

1. Introduction

Rotator cuff tears are increasingly prevalent in an aging population [Yamaguchi et al., 2006; Tempelhof et al., 2009; Yamamoto et al., 2010] and these tears can be associated with significant disability and pain [Kim M. et al., 2009; Yamaguchi et al., 2001]. A better understanding of the anatomy and function of the muscles comprising the rotator cuff may impact non-operative management of rotator cuff tears. Many muscles within the body have demonstrated distinct neuromuscular sub-regions including supraspinatus, which has an anterior and a posterior sub-region, [Kim S. et al., 2007; Roh et al., 2000] and infraspinatus, which has superior, middle, and inferior sub-regions [Bacle et al., 2017; Fabrizio & Clemente; 2014]. These sub-regions are both anatomically distinct and have innervation by individual nerve branches that give them the potential to carry out unique functions or task-oriented roles [English & Segal, 1993]. Further investigation with respect to the function of these sub-regions is necessary to better target our clinical interventions for rotator cuff tears.

When pursuing rehabilitation of rotator cuff tears one objective should be to prevent worsening of the initial injury as larger tears are more likely to be symptomatic [Yamaguchi et al., 2006]. A recent study by Miller et al. used a three-dimensional model of supraspinatus to predict propagation of rotator cuff tears with consideration given to the anterior and posterior sub-regions [Miller et al., 2017]. In their model, tears in the anterior sub-region were more likely to propagate and at lower loads than tears located in the posterior sub-region. Exercise therapy is a common and often effective treatment for rotator cuff tears [Kuhn et al., 2013], but little consideration has been given as to how rehabilitation protocols affect each of these sub-regions on an individual basis. Given that the sub-regions of supraspinatus and infraspinatus have the ability for independent functioning, preferentially targeting one sub-region over another with exercise therapy could prevent unnecessary stress in a vulnerable area, for example, a sub-region where a tear is located.

Recent studies utilizing electromyography (EMG) suggest the relative contributions of the two sub-regions of supraspinatus differ depending on the arm posture in static [Kim S. et al., 2017; Alenabi et al., 2019] and dynamic [Cudlip & Dickerson, 2018] tasks. The sustained activity of the posterior sub-region throughout experimental tasks suggests it is acting as a glenohumeral stabilizer [Alenabi et al., 2019; Cudlip & Dickerson, 2018]. Similarly, investigations regarding the activation of sub-regions of infraspinatus during isometric arm elevation tasks found that the superior sub-region of infraspinatus was more highly activated at flexion in 90° of elevation when compared to the middle sub-region [Alenabi et al., 2019]. In these studies, a limited number of arm postures were investigated and none involved the use of free weights. Therefore, there is a need to study the activation of these sub-regions during a greater number of dynamic exercises that are commonly used to treat rotator cuff pathologies.

One of the challenges in EMG investigation for dynamic tasks is the choice of normalization method. Currently, there is no clear consensus whether isometric or dynamic maximal voluntary contractions (MVCs) should be used to normalize EMG data obtained during dynamic tasks [Burden, 2010] with both methods being recognized within the Standards for Reporting EMG Data in the Journal of Electromyography and Kinesiology [Merletti, 1999]. A concern often raised with using isometric MVCs to normalize data from a dynamic task, is that previously, values greater than 100% for the experimental task have been reported [Jobe et al., 1984]. A study comparing isometric to isokinetic MVCs for a dynamic task involving shoulder musculature suggested that using an isokinetic MVC is more appropriate as it generally resulted in greater electrical activity [Hodder & Keir, 2013]. As more studies investigating the sub-regions of supraspinatus and infraspinatus are conducted, it is important to establish how the normalization method used affects data interpretation in order to compare results between studies accurately.

Thus, the goal of this study was two-fold: i) To use EMG to investigate the electrical activity within sub-regions of supraspinatus and infraspinatus during dynamic tasks commonly used in shoulder rehabilitation exercise programs and to compare the activation of one sub-region relative to the other within the same muscle. ii) To explore how these activation ratios are affected when the data were normalized by isometric versus isokinetic MVCs. Our hypotheses were that the sub-regions of supraspinatus and infraspinatus would have different relative activations based on the task performed and data interpretation would be influenced by normalization method.

2. Methods

2.1 Design

EMG activity were collected from sub-regions of the supraspinatus and infraspinatus muscles through indwelling fine-wire electrodes during abduction, scaption, flexion, and external rotation (ER) tasks performed using free weights. The relative activation of these sub-regions within each muscle was then compared based on load, task performed, and by normalization method using one-way repeated measure ANOVAs.

2.2 Participants

Fifteen healthy participants (mean age 34±12.37 yr/ height 170 cm/ weight 71.9 kg; 4M/11F) were recruited for this study. Exclusion criteria included previous shoulder pathology, neuromuscular conditions, implanted devices, cardiovascular conditions, bleeding disorders, and use of anti-coagulant medications. The University of Saskatchewan Biomedical Research Ethics Board approved this study (Bio# 13-44) and written informed consent was obtained from all participants prior to testing.

2.3 Intramuscular electromyography

All electrode insertions were performed by the same researcher, who was experienced in fine-wire EMG techniques for the shoulder. For the supraspinatus, fine-wire electrodes were inserted into the sub-regions using a previously established protocol [Kim S. et al., 2017]. Given the depth of the supraspinatus, custom-made bipolar electrodes were inserted into the anterior and posterior regions of supraspinatus using 90 mm and 23 gauge hypodermic needles (Quinke Point, Kimberly-Clark Spinal QP Needle), while commercial sterile single use hypodermic needles of 50 mm in length and 25 gauge paired fine-wire needle electrodes (Product # 000-318-150, Motion Lab Systems, Inc., Baton Rouge, LA) were used in the superior, middle, and inferior sub-regions of infraspinatus. Placements were completed using methods used by Alenabi et al. [Alenabi et al., 2018]. Indwelling electrode placement for the anterior and posterior regions of supraspinatus was guided and confirmed by ultrasound (12 MHz linear array transducer; GE Logic E, GE Medical Systems, Milwaukee, Wisconsin, U.S.A). All wires were taped to the skin and connected to a Trigno™ spring contact sensor which sampled at 2000 Hz (Delsys®, Inc. MA, USA). Two Trigno IM surface sensors were placed on the deltoid and coracoid process.

2.4 Maximal Voluntary Contractions

Participants performed both isometric and isokinetic MVCs:

- Isometric MVCs

Three isometric MVCs were performed: abduction in the frontal plane (isometric abduction), abduction in the scapular plane (isometric scaption), and external rotation (isometric ER). Full details regarding isometric MVCs may be found in Table 1 along with visual representation in Figure 1. The participant was instructed to ramp up his or her effort over the first second, hold at peak exertion for three seconds, and then release over the last second while a research assistant applied resistance [Chaffin 1975].

- Isokinetic MVCs

Three isokinetic MVCs were performed using a Humac NORM dynamometer (CSMi, Stoughton, MA, USA), as follows: scaption (isokinetic scaption), external rotation with the arm abducted to 30° and elbow flexed to 90° (isokinetic ER30°), and external rotation with the arm abducted to 90° and elbow flexed to 90° (isokinetic ER90°), in two angular speeds: 30°/sec second (slow) and 90°/sec (fast) (See Table 1 and Figure 1).

*** Insert Table 1 here***

Insert Figure 1 here

2.5 Experimental Protocol

Six shoulder exercises were selected for testing: external rotation with the arm in 90° humeral abduction while seated (ER90° seated), external rotation in side lying (ER side lying), external rotation with the arm in 90° humeral abduction while lying prone (ER90° prone), shoulder abduction in standing (abduction), shoulder flexion in standing (flexion), and shoulder scaption in standing (scaption). Full details regarding participant body postures for these tasks are outlined in Table 2 and visually demonstrated in Figure 2.

Insert Table 2 here

*** Insert Figure 2 here***

Participants attended two sessions on different days with a minimum of five days rest between sessions. The first day established the load for the five repetition maximum (5RM) for each task, and on the second day EMG data were collected while performing the same tasks in loaded and unloaded conditions.

Tasks were divided into two categories by body posture: those performed in standing or seated postures and those performed lying. The tasks were then randomized by exertion type (external rotation versus abduction/scaption/flexion). Acquisition of 5RM for each task mirrored methods published by Reynolds et al. [Reynolds et al., 2006]. If multiple attempts were needed to find 5RM for a given task, a minimum two-minute break was enforced before subsequent attempts with a greater load. If required, participants completed as many repetitions as they could using the third selected load and the 5 RM was calculated using the following formula: Step 1: 1+ (0.033 x reps) x weight = 1 RM Step 2: 0.8 x 1RM = 5 RM [American College of Sports Medicine 2017]. This was done to minimize the effects of fatigue and was only required by one participant for one task.

During the second day of testing, intramuscular electrodes were inserted and participants completed isometric and isokinetic MVCs (Table 1). All MVCs were randomized before two repetitions of each MVC were performed with a minimum of two minutes of rest provided between exertions. Two repetitions of each MVC were conducted to improve reliability [Fischer et al., 2010]. A quiet trial with the participant resting in prone for a minimum of ten seconds was also collected. Participants then performed five repetitions of the same tasks from the first session with no weight and with a hand weight corresponding to 50% and 75% of their 5RM rounded up to the nearest half pound (See Table 2). Tasks were block randomized by body posture, before being randomized by exertion type and load. A minimum one-minute rest was provided between loaded repetitions with additional time provided if requested by the participant.

2.6 Data processing

All signals were analyzed in the amplitude domain and processed using custom MATLAB code (Matlab R2017, Mathworks Inc., Natick, MA). A high pass 4th order Butterworth filter with a cutoff frequency of 30Hz was applied to all signals to remove potential heart rate contamination [Drake & Callaghan, 2006]. The signals were then full-wave rectified and low-pass single pass filtered using a 2nd order Butterworth filter with a 4Hz cutoff frequency [Winter 2009]. Normalized resting activation as determined from the quiet trial was subtracted from the protocol trials. The peak from a 500 ms moving window average of linear enveloped data was used to normalize respective linear enveloped EMG channels [Winter, 1991]. The data from each trial was normalized to isometric, slow isokinetic, and fast isokinetic region-specific MVCs. Activation ratios were calculated within a muscle by representing the activation of a given region as part of the total muscle activation for that specific task where total muscle activation is the sum of both sub-regions and equal to 1. For example, anterior supraspinatus regional activation was calculated as the normalized mean anterior supraspinatus activation (*aSUP*) divided by the combined normalized mean activation of the anterior (*aSUP*) and posterior supraspinatus (*pSUP*) (Eq.1).

$$\frac{aSUP}{(aSUP + pSUP)}\ x\ 100 \qquad (1)$$

3. Statistical Analysis

All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, U.S.A.). Activation ratios comparing sub-regions of infraspinatus to sub-regions of supraspinatus were not performed; only within muscle comparisons were performed. A preliminary analysis was performed to assess interactions between tested factors, but all were nonsignificant. Accordingly, the subsequent analysis focused on testing direct influences of the three factors of load level, task performed, and EMG normalization method on activation ratios as described below.

Three separate analyses were conducted:

i) To investigate the effect of different loads, mean activation ratios for sub-regions of supraspinatus and infraspinatus were compared across all three loads for each task (Abduction, Scaption, Flexion, ER90° seated, ER side lying, ER90° prone) using six individual one-way repeated measure ANOVAs. Alpha level was adjusted to 0.0167 (0.05/3 loads) using a Bonferroni correction. Since mean activation ratios for infraspinatus and supraspinatus were normalized to isometric and isokinetic MVCs (five normalizations for infraspinatus: isometric ER, isokinetic ER30° fast, isokinetic ER30° slow, isokinetic ER90° fast, and isokinetic ER90° slow, and three for supraspinatus: isometric abduction, isokinetic scaption fast, isokinetic scaption slow), individual one-way repeated measure ANOVAs were further conducted to account for these normalization methods. Regardless of normalization method used, there were no differences in mean activation ratios between loads. Thus, for all subsequent analyses, the loads for a given task were combined and considered as a single group.

ii) To compare the effect that each task had on the activation ratios for the sub-regions of supraspinatus and infraspinatus, mean activation ratios for the six tasks (with loads grouped) were compared using a one-way repeated measures ANOVA. A total of eight individual one-way repeated measure ANOVAs were performed; one for each isometric and isokinetic normalization method employed (five normalization methods for infraspinatus, and three for supraspinatus). Bonferroni-corrected *P*-value was 0.0083 (0.05/6 tasks).

iii) To compare the effect normalization methods had on the mean activation ratios for the sub-regions of supraspinatus and infraspinatus, one-way repeated measures ANOVAs comparing each normalization method across a single task were performed. For example, when looking at supraspinatus sub-regions, mean activation ratios for the abduction task were compared as normalized to isometric scaption, isokinetic scaption slow, and isokinetic scaption fast. For infraspinatus, Bonferroni-corrected *P*-value 0.01 (0.05/5 normalization methods) was used and for supraspinatus *P*-value 0.0167 (0.05/3 normalization methods) was used.

4. Results

Significant differences in regional muscle activation ratios were found for both supraspinatus and infraspinatus sub-regions based on normalization method and when comparing activation ratios between tasks.

4.1 Data normalized by isometric MVCs

Significant differences in the relative activation of infraspinatus sub-regions were observed when comparing tasks. There was relatively greater activation of the superior sub-region of infraspinatus when comparing ER90° prone to flexion and scaption tasks (*P*=0.0002, 0.0007) and ER side lying to flexion and scaption tasks *(P=*0.0011, 0.0035) (see Figure 3A). No significant differences in regional activation ratios between tasks were found for sub-regions of supraspinatus when normalized to the isometric MVC (Figure 4A).

4.2 Data normalized by isokinetic MVCs

When normalized to each of the isokinetic MVCs, similar findings were present with significantly greater relative activation of superior infraspinatus in ER90° prone compared to flexion and scaption tasks. This is demonstrated in Figure 3 B-E. A significantly greater relative activation of superior infraspinatus was also seen when comparing ER side lying to flexion and scaption tasks when normalized to isokinetic ER30° slow (*P*=0.0004, 0.0035) and isokinetic ER90° slow (*P*=0.0001, 0.0008), as well as ER side lying compared to flexion when normalized to isokinetic ER30° fast (*P*=0.0012). The inferior sub-region of infraspinatus was excluded from analysis due to inconsistent EMG signal pickup during testing.

When using the isokinetic scaption fast MVC to normalize supraspinatus data, there was significantly greater relative activation of posterior supraspinatus during ER side lying compared to scaption, ER90° prone, and ER90° seated *(P*=0.0012, 0.0013, 0.0021). When normalized to isokinetic scaption slow, there was greater relative activation of posterior supraspinatus in ER side lying compared to ER90° prone, ER 90° seated, abduction, scaption, and flexion (*P*=0.0017, 0.0017, 0.0057, <0.0001, 0.0034). See Figure 4 B-C.

Insert Figure 3 and 4 here

4.3 Comparing normalization methods

For most tasks, activation ratios did not significantly differ across normalization methods. However, the anterior sub-region of supraspinatus had greater relative activation in ER side lying when normalized to the isometric MVC as compared to the isokinetic scaption fast MVC (*P*=0.0096). For infraspinatus, there was greater relative activation of superior infraspinatus in flexion when normalized to isometric MVC as compared to isokinetic ER90° slow (*P*= 0.0052). See Table 3 and 4.

*** Insert Table 3 and 4 ***

5. Discussion

This study aimed to compare the relative activation of each sub-region within supraspinatus and infraspinatus muscles during various dynamic tasks with three load conditions and also investigate if different normalization methods could affect data interpretation. In agreement with our hypotheses, relative activation for sub-regions of supraspinatus and infraspinatus differed significantly based on task performed and normalization method affected EMG data interpretation. For all sub-regions, activation ratios did not differ based on load used during the task.

5.1 Infraspinatus Sub-regions

The superior sub-region of infraspinatus had significantly greater relative activation during the ER90° prone task compared to flexion and scaption tasks regardless of normalization method. Superior infraspinatus also had increased relative activation when comparing ER side lying to flexion and scaption postures when normalized to isometric, ER30° slow, and ER90° slow MVCs. Regardless of whether the arm was held close to the body (ER side lying), or elevated to 90° abduction (ER90° prone), the tendency for greater relative activation of superior infraspinatus remained when compared to flexion and scaption. Previous anatomical studies have demonstrated an overlap in the insertional footprint of supraspinatus and infraspinatus [Clark & Harryman, 1992; Minagawa et al., 1998], with one study commenting on interdigitation of muscle fibers of the posterior aspect of supraspinatus and superior aspect of infraspinatus [Curtis et al., 2006]. It is hypothesized that superior infraspinatus, along with posterior supraspinatus whose tendon it is closely related to, may help to quickly adjust tension on the rotator cuff during dynamic movements rather than act as a primary force producer [Hermenegildo et al., 2014, Kim S. et al., 2013]. During flexion and scaption, the posterior aspect of the capsule has more inherent tension placed on it than during external rotation. The greater relative activation of superior infraspinatus during external rotation may be due to this increased need for tensioning to prevent the cuff from buckling during movement. Performing ER tasks that preferentially activate the superior sub-region to a greater degree may allow for increased strengthening of this sub-region and improved ability to tension the rotator cuff.

5.2 Supraspinatus Sub-regions

There was significantly greater relative activation of posterior supraspinatus in the ER side lying posture compared to all other postures tested when normalized to isokinetic MVCs. With the ER side lying task, the arm is held close to the body compared to the other postures where the arm is in some degree of elevation during the task. This pattern persisted whether the arm was elevated in a supported posture, such as with ER90° prone or ER90° seated, or with the flexion, abduction, and scaption postures where the arm was initially close to the body before the shoulder was actively elevated. This does not necessarily mean that the posterior supraspinatus is less active at increasing elevation angles, but perhaps the anterior supraspinatus is relatively more active at increasing arm elevations. This is supported by a recent study by Cudlip and Dickerson (2018) that reported the anterior supraspinatus contributes more with increasing load and with increasing elevation angles during both isometric and dynamic tasks. Posterior supraspinatus may be relatively more active in the ER side lying posture as anterior supraspinatus is not required to act as a large force producer in contributing to elevation of the arm. These findings may be applied practically when developing rehabilitation protocols for rotator cuff tears. If a tear in the anterior supraspinatus is identified, it may be more appropriate to select external rotation tasks performed with less elevation of the arm to lower stress through the affected sub-region.

5.3 Effect of load

There were no significant changes in the regional activation ratios for supraspinatus and infraspinatus when a task was performed with no load, 50% of 5RM, or 75% of 5RM. If both sub-regions within a muscle have increased activation with an increased external load, the ratio of contribution by each sub-region may not change. A previous study that examined EMG activity of shoulder muscles during submaximal exertions performed in six directions with five hand locations demonstrated muscle activity scaled linearly with increased force [Meszaros et al., 2018]. Based on the results of our study, this may apply to sub-regions of muscle as well.

5.4 Using isokinetic vs isometric MVCs to normalize data

Previous studies examining the effects of isometric, isokinetic eccentric, and isokinetic concentric MVCs on anatagonist muscle data have produced opposing results, with Kellis and Baltzopoulous [Kellis & Baltzopoulous, 1996] finding that muscle action, length, and angular velocity did affect electromyography data interpretation, and Burden et al. [Burden et. al, 2003] finding no difference. Within our study, using isometric versus isokinetic MVCs resulted in significant differences in activation ratios when comparing some tasks, including comparing isometric scaption to isokinetic scaption fast and isometric ER to isokinetic ER90° slow. Normalizing to isometric MVCs resulted in greater relative activation for anterior supraspinatus and superior infraspinatus with subsequent decreases in relative activation when normalized to isokinetic MVCs for these tasks. This suggests that isokinetic MVCs may produce greater electrical activity for anterior supraspinatus and superior infraspinatus, and thus serve as a more effective MVC for these sub-regions. Previous studies have suggested that isometric scaption in higher elevation angles could elicit high activation for both supraspinatus sub-regions [Kim S. et al. 2017] and the posterior sub-region may contribute more in lower elevation angles [Alenabi et al. 2018]. As the isokinetic MVCs for supraspinatus started with the arm by the side before elevation to 110° in the scapular plane, the subject moved through 0°, 60° and 90° of scapular elevation while completing the task. Thus, our isokinetic MVC potentially served as a more balanced MVC for both sub-regions of supraspinatus and produced greater maximal electrical activity. A similar theory may be applied to infraspinatus. The isokinetic MVCs selected for this study were concentric in nature and matched the type of exertion used in our experimental tasks, but it is unclear what effect this may have had on our results with further study needed in this area.

These potential changes in maximal activity did not seem to affect the activation ratios when comparing between different tasks because it is the relative difference in activation that is of interest, rather than the percentage of maximal activity. For infraspinatus, similar significance patterns were found when comparing regional activation ratios across tasks regardless of normalization method employed. For supraspinatus, no significant differences in the regional activation ratios were found when normalized to an isometric MVC, but the data followed the same trend as the data normalized to isokinetic MVCs. If percentage of MVC is the outcome of interest for a study, obtaining as close to a true maximal excitation as possible is critical to representing these results accurately. Further study specifically comparing which of isometric or isokinetic MVCs produce greater electrical activity for these sub-regions are needed. If the difference in activation between tasks is the outcome of interest, using isometric or isokinetic MVCs may be appropriate for infraspinatus.

5.5 Limitations

Several limitations should be considered when contextualizing the results. The invasive nature of indwelling EMG data collection, as well as the multi-day time commitment required, resulted in a modest sample size. This was also a convenience sample and power analysis was not performed. The initial intention was to collect and analyze data from all three sub-regions within infraspinatus; unfortunately, excessive movement of the electrode within inferior infraspinatus generated a lack of consistency in the data collected from this sub-region, precluding it from analysis. This issue has also been reported in other studies aiming to collect data from inferior infraspinatus and future studies that aim to study this specific sub-region may consider alternate methods of electrode insertion [Alenabi et al., 2018].

6. Conclusion

The study explored potential differences in regional activation of the sub-regions of supraspinatus and infraspinatus during dynamic tasks. Using fine-wire EMG, differences in the regional activation of anterior supraspinatus relative to posterior supraspinatus and superior infraspinatus to middle infraspinatus were obtained during a variety of external rotation and abduction tasks performed with free weights. Posterior supraspinatus was relatively more involved in external rotation performed in a side lying posture compared to external rotation performed in other postures as well as flexion, and scaption. Superior infraspinatus was relatively more involved in external rotation, regardless of the degree of arm elevation, when compared to flexion. This study provides support for task-specific regional activation differences within supraspinatus and infraspinatus and could inform exercises selected for rehabilitation protocols for rotator cuff tears if targeting a specific sub-region is desired.

Choice of isokinetic versus isometric MVC may affect maximal electrical activity for these sub-regions, and is an important consideration moving forward if percentage MVC is an outcome of interest. Given the high prevalence of rotator cuff tears, further study investigating the sub-regions of supraspinatus and infraspinatus are needed to improve our non-operative management and choice of MVC technique should be considered in study design.

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References:

Alenabi T, Whittaker R, Kim SY, Dickerson CR. Arm posture influences on regional supraspinatus and infraspinatus activation in isometric arm elevation efforts. Journal of Electromyography and Kinesiology 2019; 44:108-116

Alenabi T, Whittaker R, Kim SY, Dickerson CR. Maximal voluntary isometric contraction tests for normalizing electromyographic data from different regions of supraspinatus and infraspinatus muscles: Identifying reliable combinations. Journal of Electromyography and Kinesiology 2018;41:19-26

American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. 10th ed. Philadelphia: Wolters Kluwer 2017

Bacle G, Gregoire J, Patat F, Clavert P, Pinieux G, Laulan J, Lakhal W, Favard L. Anatomy and relations of the infraspinatus and the teres minor muscles: a fresh cadaver dissection study. The Journal of Surgical and Radiologic Anatomy 2017;39:119-26

Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. Journal of Electromyography and Kinesiology 2010;20:1023-35

Burden A, Trew M, Baltzopoulos V. Normalisation of gait EMGs: a re-examination. Journal of Electromyography and Kinesiology 2003;13:519-532

Chaffin D. Ergonomics Guide for the Assessment of Human Static Strength. American Industrial Hygiene Association Journal 1975;36(7):505-11

Clark J, Harryman D. Tendons, Ligaments, and Capsule of Rotator Cuff. The Journal of Bone and Joint Surgery 1992. 74-A(5):713-25

Cudlip A, Dickerson CR. Regional activation of anterior and posterior supraspinatus differs by plane of elevation, hand load and elevation angle. Journal of Electromyography and Kinesiology 2018;43:14-20

Curtis A, Burbank K, Tierney J, Scheller A, Curran A. The Insertional Footprint of the Rotator Cuff: An Anatomic Study. Arthroscopy: The Journal of Arthroscopic and Related Surgery 2006;22(6):603-9

Drake J, Callaghan J. Elimination of electrocardiogram contamination from electromyographic signals: An evaluation of currently used removal techniques. Journal of Electromyography and Kinesiology 2006;16:175-87

English A, Wolf S, Segal R. Compartmentalization of Muscles and Nuclei: The Partitioning Hypothesis. Physical Therapy 1993; 73(12): 857-867

Fabrizio P, Clemente R. Anatomical structure and nerve branching pattern of the human infraspinatus muscle. Journal of Bodywork & Movement Therapies 2014;18:228-32

Fischer S, Belbeck A, Dickerson CR. The influence of providing feedback on force production and within-participant reproducibility during voluntary exertions for the anterior deltoid, middle deltoid, and infraspinatus. Journal of Electromyography and Kinesiology 2010;20:68-75

Hermenegildo J, Roberts S, Kim S. Innervation Pattern of the Suprascapular Nerve Within Supraspinatus: A Three-Dimensional Computer Modeling Study. Clinical Anatomy 2014;27:622-30

Hodder J, Keir P. Obtaining maximal muscle excitation for normalizing shoulder electromyography in dynamic contractions. Journal of Electromyography and Kinesiology 2013;23:1166-73

Jobe F, Moynes D, Tibone J, Perry J. An EMG analysis of the shoulder in pitching A second report. The American Journal of Sports Medicine 1984;12(3):218-20

Kellis E, Baltzopoulos V. The Effects of Normalization Method On Antagonistic Activity Patterns During Eccentric and Concentric Isokinetic Knee Extension and Flexion. Journal of Electromyography and Kinesiology 1996;6(4):235-45

Kim M, Teefey S, Zelig A, Galatz L, Keener J, Yamaguchi K. Shoulder Strength in Asymptomatic Individuals with Intact Compared with Torn Rotator Cuffs. The Journal of Bone and Joint Surgery 2009;91:289-96

Kim S, Boynton E, Ravichandiran K, Fung L, Bleakney R, Agur A. Three-Dimensional Study of the Musculotendinous Architecture of Supraspinatus and Its Functional Correlations. Clinical Anatomy 2007;20:648-55

Kim SY, Ko J, Dickerson CR, Collins DF. Electromyographic investigation of anterior and posterior regions of supraspinatus: a novel approach based on anatomical insights. International Biomechanics 2017;4(2):60-7

Kim S, Lunn D, Dyck R, Kirkpatrick L, Rosser B. Fiber type composition of the architecturally distinct regions of human supraspinatus muscle: A cadaveric study. Histology and Histopathology 2013;28:1021-28

Kuhn J, Dunn W, Sanders R, An Q, Baumgarten K, Bishop J, Brophy R, Carey J, Holloway B, Jones G, Ma B, Marx R, McCarty E, Poddar S, Smith M, Spencer E, Vidal A, Wolf B, Wright R. Effectiveness of physical therapy in treating atraumatic full-thickness rotator cuff tears: a multicenter prospective cohort study. Journal of Shoulder and Elbow Surgery 2013; 22:1371-1379

Miller M, Thunes J, Musahl V, Maiti S, Debski R. Effect of tear size and location on predictions of supraspinatus tear propagation. Journal of Biomechanics 2017; 68:51-57

Minagawa H, Itoi E, Konno N, Kido T, Sano A, Urayama M, Sato K. Humeral attachment of the Supraspinatus and Infraspinatus Tendons: An Anatomic Study. Arthroscopy: The Journal of Arthroscopic and Related Surgery 1998;14(3):302-6

Merletti, R. Standards for Reporting EMG data. Journal of Electromyography and Kinesiology 1999; 9(1):3-5

Meszaros K, Vidt M, Dickerson CR. The effects of hand force variation on shoulder muscle activation during submaximal exertions. International Journal of Occupational Safety and Ergonomics 2018; 24(1):100-10

Reynolds J, Gordon T, Robergs R. Prediction of One Repetition Maximum Strength From Multiple Repetition Maximum Testing and Anthropometry. Journal of Strength and Conditioning Research 2006; 20(3):584-592.

Roh M, Wang V, April E, Pollock R, Bigliani L, Flatow E. Anterior and posterior musculotendinous anatomy of the supraspinatus. Journal of Shoulder and Elbow Surgery 2000;9(5):436-40

Tempelhof S, Rupp S, Seil R. Age-related prevalence of rotator cuff tears in asymptomatic shoulders. Journal of Shoulder and Elbow Surgery 1999; 8(4):296-99

Winter D. Biomechanics and Motor Control of Human Movement. 4th ed. New Jersey: John Wiley & Sons, Inc., 2009

Winter D. Electromyogram recording, processing, and normalization: Procedures and considerations. Journal of Human Muscle Performance 1991;1:5-15

Yamaguchi K, Ditsios K, Middleton W, Hildebolt C, Galatz L, Teefey S. The Demographic and Morphological Features of Rotator Cuff Disease: A comparison of asymptomatic and symptomatic shoulders. The Journal of Bone and Joint Surgery 2006; 88-A(8):1699-1704

Yamaguchi K, Tetro A, Blam O, Evanoff B, Teefey S, Middleton W. Natural history of asymptomatic rotator cuff tears: A longitudinal analysis of asymptomatic tears detected sonographically. Journal of Shoulder and Elbow Surgery 2001; 10(3):199-203

Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, Kobayashi T. Prevalence and risk factors of a rotator cuff tear in the general population. Journal of Shoulder and Elbow Surgery 2010; 19:116-120

Fig. 1. Visual representation of isometric and isokinetic MVCs: isometric abduction (A), isometric scaption (B), isometric ER (C), isokinetic scaption (D), isokinetic ER30° (E), isokinetic ER90° (F). For isokinetic MVCs two speeds were used (30°/sec = slow, 90°/sec =fast), with the start position demonstrated within the figure. Full details regarding MVC postures may be found in Table 1

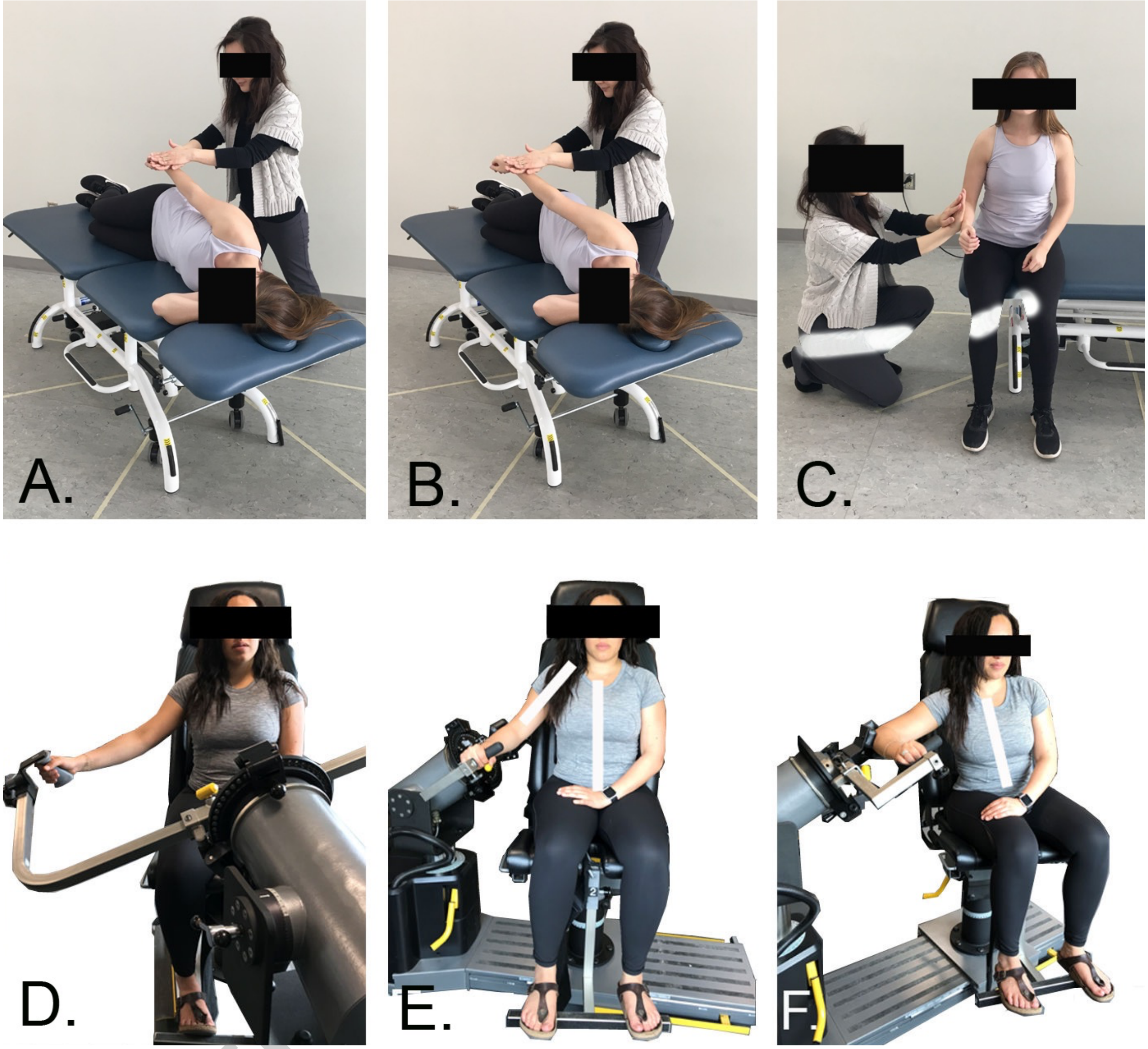
Fig. 2. Visual representation of experimental tasks: Abduction (A), Scaption (B), Flexion (C), ER90° seated (D), ER side lying (E), and ER90° prone (F). Plane of elevation is marked on the floor to help guide participants during the task (A-C). Full details regarding tasks are available in Table 2.

Fig. 3. Comparison of mean estimates between tasks for infraspinatus presented according to normalization method: isometric MVC (A.), isokinetic ER30° fast MVC (B.), isokinetic ER30° slow MVC (C.), isokinetic ER90° fast MVC (D.), and isokinetic ER90° slow MVC (E.). Bars show mean estimate for the superior sub-region of infraspinatus. The mean estimate of both sub-regions will always have a sum of 100 (see equation 1), thus the mean estimate of the middle sub-region is 100 – value presented in the bar. Significant differences between tasks are represented with paired letters.

Standard error represented with bars, Corresponding significant *P*-values (<0.01) as follows: a= 0.0035, b = 0.0007, c= 0.0011, d= 0.0002, e= 0.0011, f= <0.0001, g= 0.0012, h= 0.0035, i=0.0017, j= 0.0004, k=0.0002, l= 0.0031, m=0.0013, n= 0.0008, o= 0.0003, p=0.0001, q= <0.0001

Fig. 4. Comparison of mean estimates between tasks for supraspinatus presented according to normalization method: isometric MVC (A.), isokinetic slow MVC (B.), and isokinetic fast MVC (C.). Bars show mean estimate for the anterior sub-region of supraspinatus. The mean estimate of the posterior sub-region is 100- value presented in the bar. Significant differences between tasks are represented with paired letters.

Standard error represented with bars, Corresponding significant *P*-values (<0.01) as follows: a= 0.0057, b = <0.0001, c=0.0034, d = 0.0017, e= 0.0017, f= 0.0012, g=0.0021, h = 0.0013


A.
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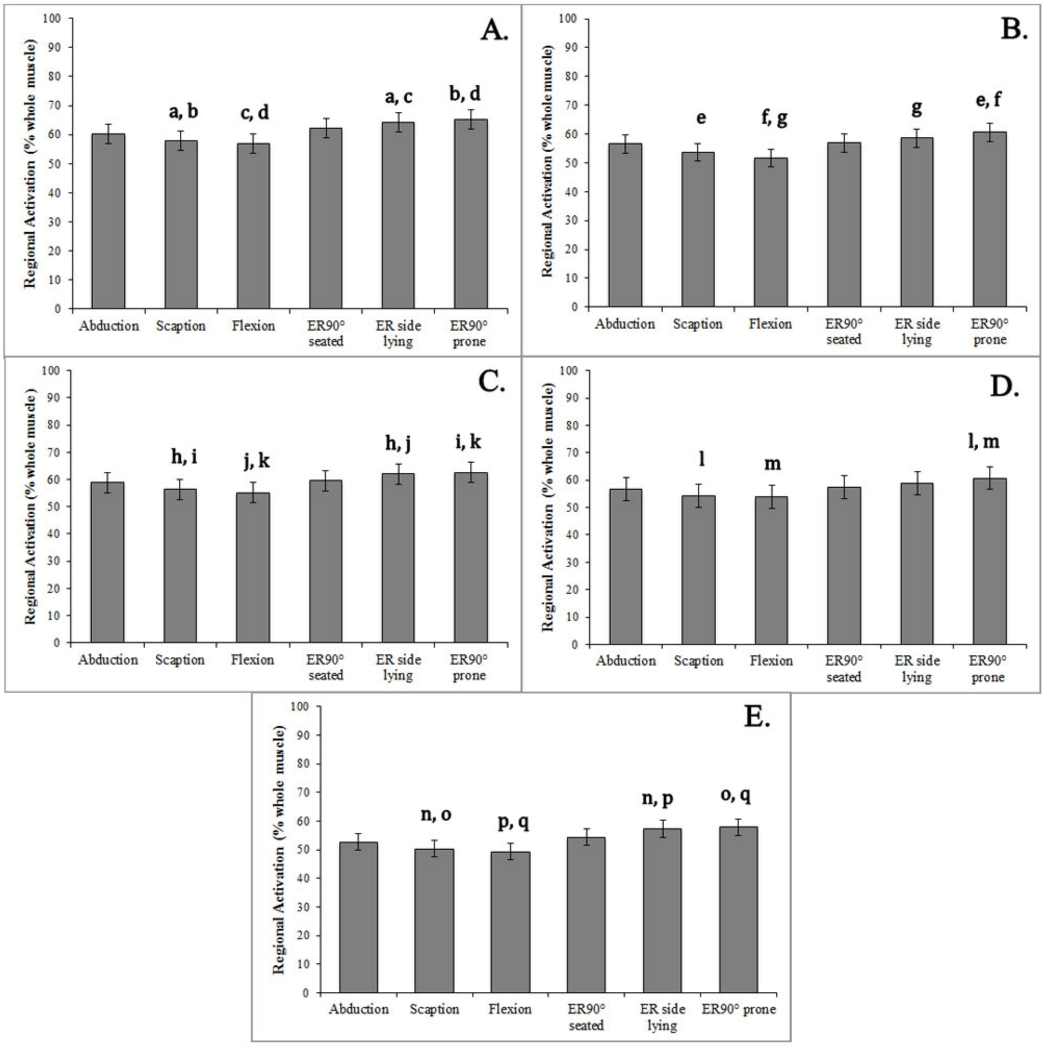
A.
B.
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Regional Activation (% whole muscle)
0
10
20
30
40
50
60
70
80
90
100
Abduction
Scaption
Flexion
ER90° seated
ER side lying
ER90° prone
a, b
c, d
a, c
b, d
e
f, g
g
e, f
h, i
j, k
h, j
i, k
l
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l, m
n, o
p, q
n, p
o, q

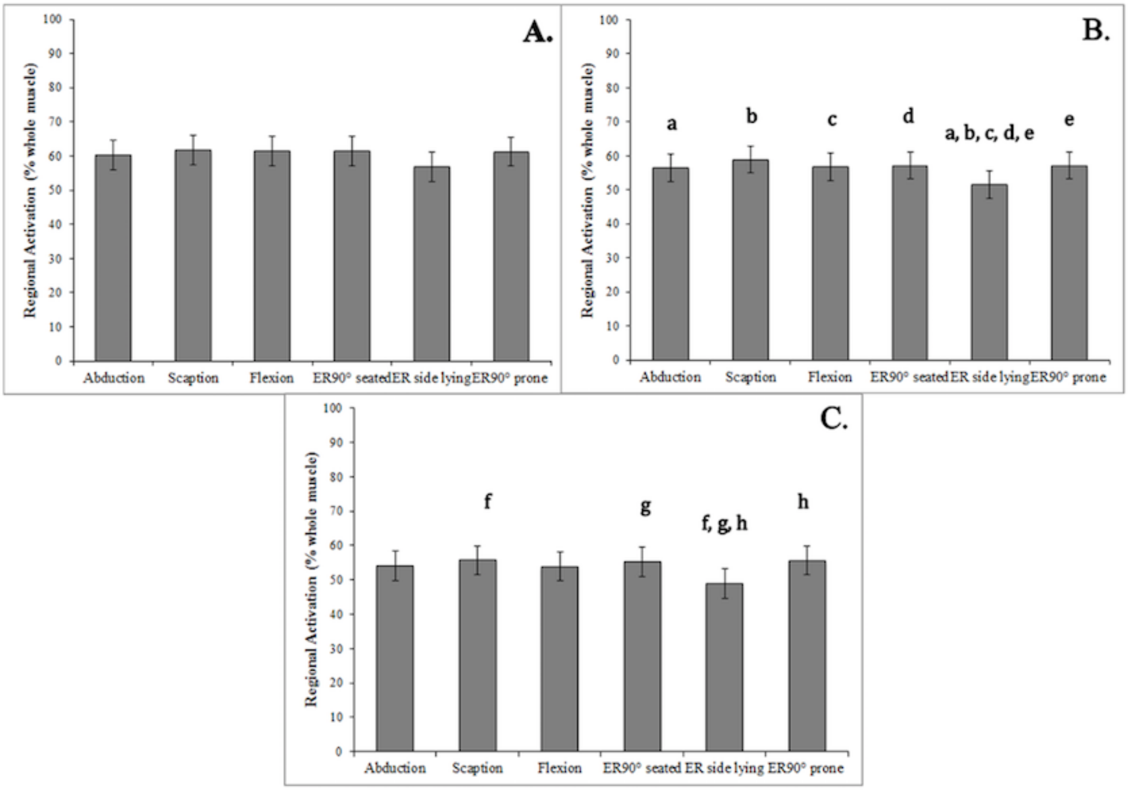

A.
B.
C.
Regional Activation (% whole muscle)
0
10
20
30
40
50
60
70
80
90
100
Abduction
Scaption
Flexion
ER90° seated
ER side lying
ER90° prone
a
b
c
d
a, b, c, d, e
e
f
g
f, g, h
h

Table 1 Descriptions of MVCs

MVC Name	Description	Angular Speed
Isometric abduction	In side lying, the arm is held in 10° of abduction with the elbow extended and external force applied at the wrist.	N/A
Isometric scaption	In side lying, the arm is held in 10° of scaption with the elbow extended and external force applied at the wrist	N/A
Isometric ER	Seated, the arm is held close to the body with 90° of elbow flexion in neutral. External force is applied at the wrist while the participant attempts to externally rotate the arm.	N/A
Isokinetic scaption	Seated on the dynamometer, the elbow is extended and handle held at lowest comfortable position with the thumb pointed up (full can). The arm is then elevated to 110° in the scapular plane.	30°/sec, 90°/sec
Isokinetic ER30 °	Seated on the dynamometer, the elbow is bent to 90° and the shoulder held in 30° abduction. External rotation is then performed to maximum comfortable range.	30°/sec, 90°/sec
Isokinetic ER90°	Seated on the dynamometer, the elbow is bent to 90° and the shoulder held in 90° abduction. External rotation is then performed to maximum comfortable range.	30°/sec, 90°/sec

Table 2 Description of Free Weight Tasks

Task Name	Description	Cadence
Abduction	Standing with the arm by the side, elevate the load from 0° to 110° in the frontal plane with the thumb up (full can) and elbow slightly flexed. Return to starting position.	50 bpm
Scaption	Standing with the arm by the side, elevate the load from 0° to 110° in the scapular plane with the thumb up (full can) and elbow slightly flexed. Return to starting position.	50 bpm
Flexion	Standing with the arm by the side, elevate the load from 0° to 110° in the sagittal plane with the thumb up (full can) and elbow slightly flexed. Return to starting position.	50 bpm
ER90° seated	Seated, the arm is held in 90° of supported abduction, with the elbow flexed to 90° and the forearm pronated. The shoulder is then externally rotated to a minimum 80% ROM for the task. Return to starting position.	60 bpm
ER side lying	Lying in left lateral decubitus, the arm is held close to the body with the elbow flexed to 90°. The start position is with the arm internally rotated and hand on abdomen. The shoulder is then externally rotated to minimum 80% ROM for the task. Return to starting position.	60 bpm
ER90° prone	Lying prone, the arm is abducted to 90° with the humerus supported mid-shaft, the elbow flexed to 90°, and the forearm pronated. The shoulder is then externally rotated to minimum 80% of ROM for the task. Return to starting position.	60 bpm

Table 3 Comparison of Mean Estimates of Regional Muscle Activation for Each Task According to Normalization Methods for Sub-regions of Supraspinatus

	Normalization Method					
Task	Isometric		Isokinetic			
			Scaption Fast		Scaption Slow	
	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior
Abduction	60.29 (2.9)	39.71 (2.9)	54.03 (2.9)	45.97 (2.9)	56.43 (2.9)	43.57 (2.9)
Scaption	61.63 (3.2)	38.37 (3.2)	55.67 (3.2)	44.33 (3.2)	58.9 (3.2)	41.10 (3.2)
Flexion	61.59 (3.4)	38.41 (3.4)	53.93 (3.4)	46.07 (3.4)	56.74 (3.4)	43.26 (3.4)
ER 90° seated	61.42 (3.5)	38.58 (3.5)	55.31 (3.5)	44.69 (3.5)	57.13 (3.5)	42.87 (3.5)
ER side lying	***56.8**** (4.0)	43.20 (4.0)	***48.96**** (4.0)	51.04 (4.0)	51.53 (4.0)	48.47 (4.0)
ER 90° prone	61.22 (3.5)	38.78 (3.5)	55.62 (3.5)	44.38 (3.5)	57.15 (3.5)	42.85 (3.5)

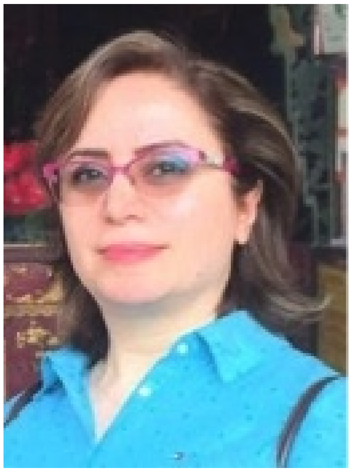
**P*=0.0096, ER= external rotation, slow was 30° deg/sec, fast was 90° deg/sec, standard error ()

Table 4: Comparison of Mean Estimates of Regional Muscle Activation for Each Task According to Normalization Methods for Sub-regions of Infraspinatus

	Normalization method									
	Isometric		Isokinetic							
			ER 30° Fast		ER 30° Slow		ER 90° Fast		ER 90° Slow	
Task	Superior	Middle	Superior	Middle	Superior	Middle	Superior	Middle	Superior	Middle
Abduction	60.35 (2.8)	39.65 (2.8)	56.55 (2.8)	43.45 (2.8)	58.88 (2.8)	41.12 (2.8)	56.58 (2.8)	43.42 (2.8)	52.71 (2.8)	47.29 (2.8)
Scaption	57.78 (2.8)	42.22 (2.8)	53.67 (2.8)	46.33 (2.8)	56.39 (2.8)	43.61 (2.8)	54.41 (2.8)	45.59 (2.8)	50.26 (2.8)	49.74 (2.8)
Flexion	***56.98**** (2.4)	43.02 (2.4)	51.67 (2.4)	48.33 (2.4)	55.07 (2.4)	44.93 (2.4)	53.81 (2.4)	46.19 (2.4)	***49.25**** (2.4)	50.75 (2.4)
ER 90° seated	62.29 (3.1)	37.71 (3.1)	56.85 (3.1)	43.15 (3.1)	59.59 (3.1)	40.41 (3.1)	57.5 (3.1)	42.5 (3.0)	54.37 (3.1)	45.63 (3.1)
ER side lying	64.17 (3.5)	35.83 (3.5)	58.60 (3.5)	41.4 (3.5)	62.13 (3.5)	37.87 (3.5)	58.78 (3.5)	41.22 (3.5)	57.26 (3.5)	42.74 (3.5)
ER 90° prone	65.27 (2.9)	34.73 (2.9)	60.65 (2.9)	39.35 (2.9)	62.59 (2.9)	37.41 (2.9)	60.76 (2.9)	39.24 (2.9)	57.8***2*** (2.9)	42.18 (2.9)

**P*= 0.0052, ER= external rotation, slow was 30° deg/sec, fast was 90° deg/sec, standard error ()

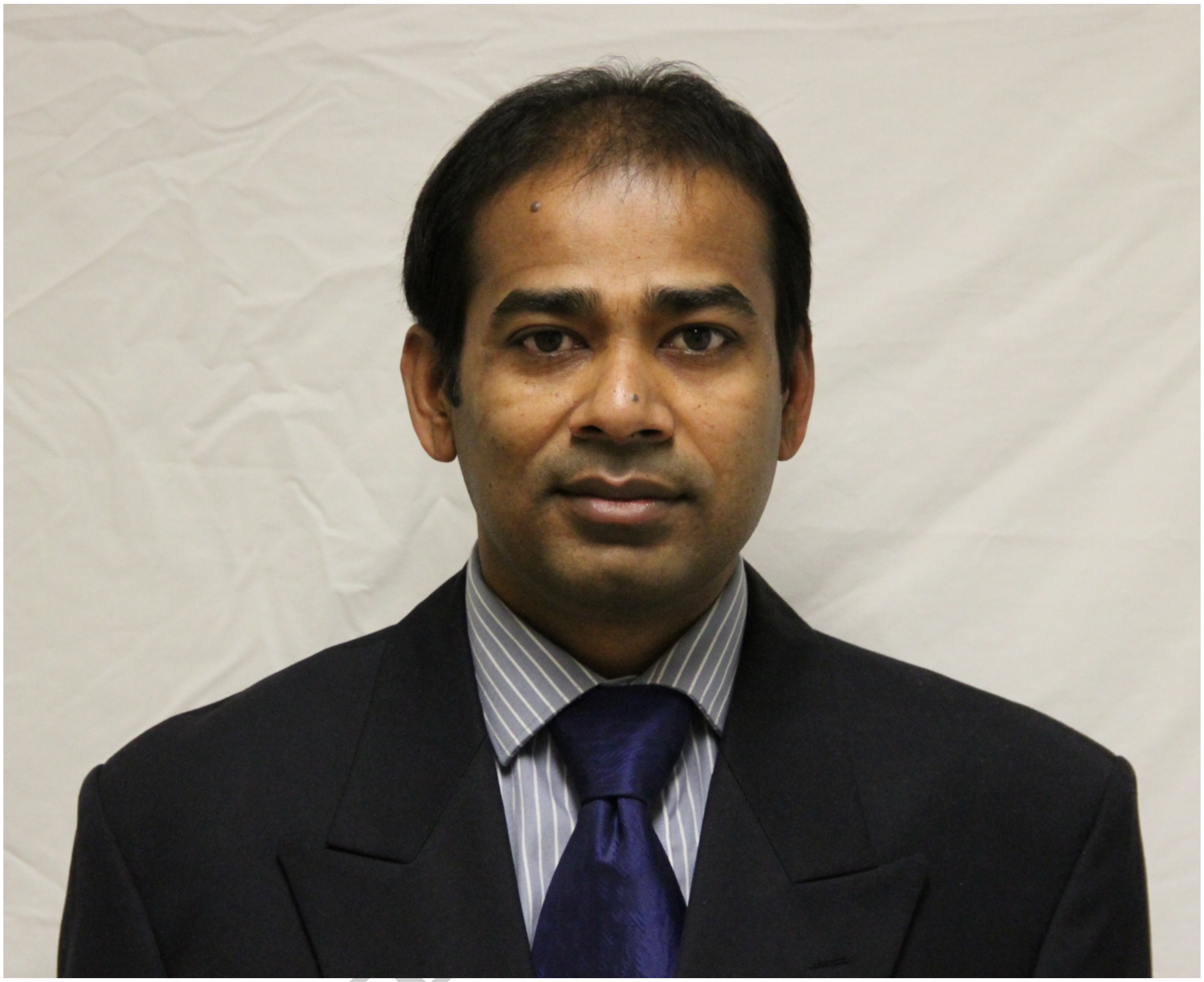
Ronelle Calver (MD) received her Doctor of Medicine from the University of Saskatchewan in 2017. She is currently completing her postgraduate training in Physical Medicine and Rehabilitation at McMaster University. Her clinical interests include stroke rehabilitation, musculoskeletal disorders, and electrodiagnostic medicine. Her research focus involves the study of anatomic sub-regions within the shoulder using electromyography and the clinical translation of these findings.



Talia Alenabi (MD, PhD) is a Post-Doctoral Fellow at the University of Waterloo, Canada. She has been a sports medicine clinician, working with elite athletes for many years. She received her MD from Tehran University of Medical Sciences, Master of science in Sports and Exercise Medicine from the Chinese University of Hong Kong and PhD in Kinesiology/biomechanics form the University of Montreal. Her research interests include rotator cuff pathologies, electromyography of shoulder musculature, prevention of shoulder injuries and disorders, work and sports related shoulder problems and rehabilitation of shoulder injuries. She has been a previous executive board member at the International Federation of Sports Medicine (2010-2014), current vice president of the Asian Federation of Sports Medicine, and a member of the Canadian Society of Biomechanics.

Alan Cudlip (MSc) is a doctoral student in the Digital Industrial Ergonomics and Shoulder Evaluation Laboratory at the University of Waterloo. His research focuses on human musculoskeletal biomechanics, particularly on fundamental shoulder mechanics. He earned his BSc and MSc at the University of Waterloo. His current research interests include rotator cuff mechanics and shoulder disorder mitigation and prevention through in vivo and in vitro methods.

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 and developmental 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.



Prosanta Mondal (PhD) is a biostatistician at the Clinical Research Support Unit (CRSU), College of Medicine, University of Saskatchewan, Canada. He received his PhD degree in biostatistics from the University of Saskatchewan and completed MSc degrees in statistics and biostatistics from Concordia University, Montreal and Old Dominion University, Virginia, respectively. Dr. Mondal has worked in the Institute of Human Virology (IHV), University of Maryland, Baltimore and Institute for Clinical Evaluative Sciences (ICES), Toronto. His research interest includes longitudinal analysis, survival analysis with competing risks, joint modeling of longitudinal measurements and survival data with competing risks.

Dr. Soo Kim is an Associate Professor at the School of Rehabilitation Science, University of Saskatchewan (U of S). She received her B.Sc. degree in Physical Therapy in 1998 from the University of Toronto. During her years as a clinician, she developed expertise in sports medicine and a special interest in shoulder rehabilitation. In 2008, she earned her PhD from the University of Toronto based on research investing the detailed muscle and tendon architecture of the supraspinatus muscle and developed of an ultrasound imaging protocol to quantify architectural changes with rotator cuff pathology. She has an active research program investigating muscle architecture and function in response to pathology, surgery, radiation and rehabilitation. She is an active member of the American Association of Clinical Anatomists and Canadian Physiotherapy Association.