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# Electromyography activation of shoulder and trunk muscles is greater during closed chain compared to open chain exercises☆

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## Abstract

**Background:** To compare the activation of shoulder and trunk muscles between six pairs of closed (CC) and open chain (OC) exercises for the upper extremity, matched for performance characteristics. The secondary aims were to compare shoulder and trunk muscle activation and shoulder activation ratios during each pair of CC and OC exercise.

**Methods:** Twenty-two healthy young adults were recruited. During visit 1, the 5-repetition maximum resistance was established for each CC and OC exercise. During visit 2, electromyography activation from the infraspinatus (INF), deltoid (DEL), serratus anterior (SA), upper, middle and lower trapezius (UT, MT, LT), erector spinae (ES) and external oblique (EO) muscles was collected during 5-repetition max of each exercise. Average activation was calculated during the concentric and eccentric phases of each exercises. Activation ratios (DEL/INF, UT/LT, UT/MT, UT/SA) were also calculated. Linear mixed models compared the activation by muscle collapsed across CC and OC exercises. A paired t-test compared the activation of each muscle and the activation ratios (DEL/INF, UT/LT, UT/MT, UT/SA) between each pair of CC and OC exercises.

**Results:** The INF, LT, ES, and EO had greater activation during both concentric ($p = 0.03$) and eccentric ($p < 0.01$) phases of CC versus OC exercises. Activation ratios were lower in CC exercises compared to OC exercises (DEL/INF, 3 pairs; UT/LT, 2 pairs; UT/MT, 1 pair; UT/SA, 3 pairs).

**Conclusion:** Upper extremity CC exercises generated greater activation of shoulder and trunk muscles compared to OC exercises. Some of the CC exercises produced lower activation ratios compared to OC exercises.

### Keywords

Activation ratio; Infraspinatus; Scapula; Serratus anterior

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Declaration of Competing Interest
None.

## 1. Introduction

Strengthening exercises of the upper extremity can be performed in either open chain (OC) or closed chain (CC). During OC exercises, the terminal segment (hand) moves the resistance, whereas in CC exercises the terminal segment is fixed and body weight provides the resistance. OC exercises can isolate single joints and movements, while CC exercises are multi-joint and multi-planar. Research in the lower extremity has shown that CC exercises promote greater proprioceptive feedback, and greater muscle activation with higher motor unit synchronization compared to OC exercises (Mellor and Hodges, 2005; Stensdotter et al., 2003). Similarly, complex movements during upper extremity CC exercises may improve intersegmental coordination and muscle activity required during functional activities of the upper extremity (Kibler and Livingston, 2001; Lephart and Henry, 1996; Prokopy et al., 2008; Wright et al., 2018).

The use of a CC exercise program has translated into improved performance on an upper extremity stability test (Ubinger et al., 1999) and shoulder strength (Lee and Kim, 2016) in baseball players. Moreover, a CC exercise regime generated greater improvements in throwing velocity in softball pitchers compared to an OC program (Prokopy et al., 2008). The use of CC exercises have also demonstrated beneficial effects when used in patients with shoulder pain, with 76% achieving a clinically meaningful change in pain and disability as compared 57% in those using OC exercises (Heron et al., 2017). Electromyography (EMG) studies can aid in interpreting these findings. CC exercises generates moderate to high activation of the shoulder musculature (> 20% of maximal activation) (De Mey et al., 2014; Fenwick et al., 2009; Youdas et al., 2010), which can explain the strengthening effect of these types of exercises (Lee and Kim, 2016). Further, high activity of the trunk muscles have been reported during CC exercise (Fenwick et al., 2009; Youdas et al., 2010), which may improve activity of the shoulder muscle by enhancing the proximal kinetic chain (Vega Toro et al., 2016). Lastly, CC exercise generates greater activity of the serratus anterior, and lower and middle trapezius relative to the upper trapezius (Ludewig et al., 2004; Maenhout et al., 2010). The lower activation ratios in the scapular muscle pairs, along with the increased shoulder and trunk muscle activation, may explain the potential benefits of CC exercises on upper extremity pain and disability.

Electromyography (EMG) studies of CC exercise of the upper extremity provide either biomechanical descriptions of each CC exercise (Ludewig et al., 2004; Youdas et al., 2010), or compare different performance conditions within the same CC exercise (i.e., normal push up versus knee push up) (De Mey et al., 2014; Fenwick et al., 2009; Maenhout et al., 2010). Direct comparison of muscle activation during CC and OC exercises, matched for performance characteristics, is lacking. This detrimental gap, along with difficulty in execution and clinicians lack of familiarity with upper extremity CC exercises (Heron et al., 2017), may limit the clinical prescription of CC exercises for the upper extremity (Wright et al., 2018). The primary aim of this study was to compare the muscle activation of shoulder and trunk muscles between six pairs of CC and OC exercises for the upper extremity, matched for performance characteristics. The secondary aims were to compare shoulder and trunk muscle activation and shoulder muscle activation ratios during pairs of CC and OC exercise. It was hypothesized that CC exercises would produce: 1) greater shoulder and trunk muscle activation than exercises performed with an OC setup, and 2) lower muscle activation ratios at the shoulder.

## 2. Methods

### 2.1. Sample

A sample of convenience was recruited. Participants were included if they were at least 18 years of age and had no current shoulder pain or shoulder injuries within the past 12 months. Individuals were excluded if they reported any of the following: (1) history of shoulder surgery or fracture; (2) history of bilateral shoulder injury; (3) uncontrolled high blood pressure or diabetes; (4) cardiovascular, pulmonary, neurological disease with physician limitations on exercise; (5) current treatment for cancer; or (6) allergy to adhesive tape. All participants signed an informed consent prior to their participation in accordance with the policies of the Institutional Review Board at the University of Southern California. An *a priori* power analysis indicated that using a linear mixed effect model to compare muscle activation during CC and OC exercises using 2 exercise types (CC and OC) would require a sample size of at least 20 participants.

### 2.2. Instrumentation

The International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003) was used to assess physical activity across a comprehensive set of domains, which included three specific types of activity: walking, moderate-intensity activities, and vigorous-intensity activities. The intensity of each activity combined with the time spent on each activity was used to calculate a summative score (MET-min/week) (Craig et al., 2003). The summative score was also categorized as low, moderate, and high levels of physical activity (Craig et al., 2003).

The Quick Disabilities of the Arm, Shoulder and Hand (Q-DASH) (Beaton et al., 2005) was used to quantify shoulder disability. Participants rated interference and difficulty of daily upper extremity activities for 11 items on a 5-point Likert scale; total score 0 to 100, with 0 indicating absence of disability/full function.

Closed chain exercises were performed using a Body Weight Trainer (CKC Fitness System; Crozet, VA). OC exercises were performed using a Genesis machine (Freemotion Fitness, Logan, UT). A wooden bar was used for allow for bilateral performance, to match that of the CC exercises.

Electromyography data were acquired at 2400 Hz using an eight-channel EMG system (Bagnoli, Delsys, Natick, Massachusetts) with double-differential surface EMG electrodes (Bagnoli Sensor Skin Interface 2-slot SC-F01, Delsys Inc., Natick, MA). All raw EMG signals were preamplified using an amplifier with voltage gain of 10, noise of 1.2 μV (root mean square) and a common mode rejection ratio of 92 dB. A video camera was used to record the performance of each exercise. Video frequency was set at 30 Hz and The Motion Monitor (Version 9, Innovative Sports Inc., Chicago, Illinois) was used to synchronize EMG and video acquisition.

### 2.3. Procedures

**2.3.1. Visit 1—**Participants completed the IPAQ and Q-DASH questionnaires. Afterwards, each exercise was explained and demonstrated by one of the investigators. Five out of six CC exercises (push up, chin up, inverted row, triceps dips, and shoulder depression) required participants to work against their body weight (Table 1). If participants were not able to perform the exercise against the body weight, elastic bands (Perform Better, Cranston, RI) were used to offset the participant's weight as depicted in Table 1. Six elastic bands of varying thicknesses were used. According to manufacturer data, the resistance of the thickest band (blue) is approximately 34Kg at 10 cm length, and 95Kg at 25 cm length; the resistance of the thinnest band (orange) is approximately 2Kg at 10 cm length, and 11Kg at 25 cm length. If participants could perform the exercise against body weight, cuff weights were used to increase the resistance. One exercise (vertical press) required participants to work against the resistance provided by an elastic band. Isotonic weights were used to provide resistance in all OC exercises (horizontal press, latissimus pulldown, horizontal row, triceps curls, shoulder depression, and vertical press).

Participants were allowed to practice each CC and OC exercise with the lowest resistance. Afterwards, the resistance to be used in the test was established for each CC an OC exercise. One of the investigators monitored the execution of each exercise to ensure proper exercise form. Resistance was gradually increased until participants reached a self-reported 5-repetition maximum effort level (resistance that each participant could move for at most 5 repetitions). The 5-repetion maximum effort allowed analysis of muscle activation during the 3 middle repetitions, while discarding the first and last repetitions to accommodate for ramping up and down of the exercise. Order of exercise performance was randomized and a 1-minute rest period was given between each set of exercise.

**2.3.2. Visit 2—**The second visit was scheduled within 48 h of the first visit. Electrodes were placed on the belly of the following muscles: middle deltoid (DEL), infraspinatus (INF), serratus anterior (SA), erector spinae (ES), external oblique (EO), and upper, middle, and lower trapezius (UT, MT, and LT, respectively). Prior to electrodes application, the skin was cleaned with alcohol and gently abraded to reduce noise in the EMG data (Hermens et al., 2000). Positions for the electrodes are reported in Table 2. The electrodes were oriented parallel to the muscle fibers and attached on the dominant side of the shoulder and trunk with double sided-tape and secured with adhesive tape. If the dominant arm had history of prior shoulder injury (occurred more than 12 months prior to data collection), electrodes were placed on the contralateral arm. Dominant side was determined by asking the participant which arm they use to write. The investigator responsible for placing the EMG electrodes demonstrated reliability in collecting EMG from the abovementioned muscles during a dynamic shoulder elevation task (intraclass correlation coefficient > 0.83). Intra-session minimal detectible change for EMG of the anterior DEL, SA, UT, and LT has been established during arm elevation and ranges from 6 to 46 mV (Seitz and Uhl, 2012).

Participants performed maximal voluntary isometric contractions to calculate the maximal EMG activity of each muscle. Maximal activation of the shoulder muscles was tested in scaption, which maximizes the activity of the DEL, UT, MT, LT, and SA; and external rotation, which maximizes the activity of the INF, MT, and LT (Boettcher et al., 2008). For scaption, participants were seated with the arm positioned at 90° of flexion and 40° of abduction in the scapular plane. The elbow was extended and resistance was provided at the radial styloid. For external rotation, participants were seated with the arm in a neutrally rotated position and elbow flexed to 90°. Resistance was provided between the radial and ulnar styloid. Maximal activation of the ES was tested with participants lying prone with the hands behind their head and legs extended (Fenwick et al., 2009). One of the investigators provided stabilization of the leg at the ankle. Participants were asked to extend their trunk and resistance was provided at the upper trunk between the scapula. Maximal activation of the EO was tested with participants laying supine with their arms crossed over their chest and knees flexed at 90° with the feet on the ground (Fenwick et al., 2009). One of the investigators provided stabilization of the leg at the ankle. Participants were asked to flex their trunk and resistance was provided at the shoulder. Two maximal effort trials were performed for each test with a minute rest between trials. Participants were asked to push as hard as they could for 5 s. Verbal encouragement was provided.

Participants performed 6 exercises twice, once using a CC setup and once using an OC setup. The order of exercise setup (CC and OC) was randomized. Five-minute of rest was given at the end of the first bout of CC or OC exercises. Within each exercise setup (CC or OC), participants completed one set of 5-repetition for each exercise using the resistance established during visit 1. Exercise order was randomized, and one-minute of rest was given between each set. Participants were instructed to perform each exercise at a pace of approximately 2 s per repetition, but timing was not enforced. Before starting, a rest period of muscle activity was recorded with the participant standing in neutral position with the arm resting next to the body for 1 s.

## 2.4. Data analysis

The middle 3 repetitions during each exercise were used for analysis. The start and end of each repetition was manually identified on the video data. The investigator reliability to select the start and end of each repetition was established using 10 random exercises from 10 random participants. Results showed high reliability (intraclass correlation coefficient > 0.99). Each repetition was further sub-divided in 2 phases: concentric phase, defined as when the participant worked against gravity to actively lift their body weight or the isotonic weight of the exercise machine; eccentric phase, defined as when the participant worked against gravity to slow down the return to the starting point of the concentric phase. Detailed information on each phase, for each exercise, is reported in Table 1.

The EMG signals from the maximal voluntary contractions and from the performance of each exercise were imported into Matlab (version R2016b, Mathworks, Natick, MA, USA), band-pass filtered (20–400 Hz Butterworth, dual-pass, 2nd order), rectified and adjusted for baseline noise by subtracting the mean of the rectified signal during the quiet period (before the start of each exercise) from the rectified signal. A linear envelope was then created by applying a low pass filter (6 Hz Butterworth, dual-pass, 2nd order). An experienced investigator visually inspected all EMG signals for consistency and errors during data collection and analysis.

For the first aim of this study, the activation of each muscle during the concentric and eccentric phases was calculated by averaging the activation in mV during the middle 3 repetitions of each CC and OC exercise. For the second aim of this study, the activation of each muscle from the concentric and eccentric phases of each CC and OC exercise were averaged. This was done because clinical exercise prescriptions that include only one phase of an exercise are rare. For these analyses, EMG signals were not normalized because they were compared by muscle between exercise type (CC versus OC), within the same participant and session (Halaki and Gi, 2012). As part of the second aim, four activation ratios were calculated: (1) DEL/INF, (2) UT/MT, (3) UT/LT, and (4) UT/SA. Exercises that produce ratios lower than 1 are considered optimal for patients with shoulder disorders because they maximize activity of the INF, SA, and MT, and LT, relative to the DEL and UT (Cools et al., 2007; Ludewig and Reynolds, 2009; Maenhout et al., 2010). This interpretation requires direct comparison of activation between different muscles. Therefore, EMG signals used in the calculation of the activation ratios were normalized to activation during the maximal voluntary contraction (Halaki and Gi, 2012).

## 2.5. Statistical analysis

All statistical analyses were performed in Matlab. Descriptive statistics, mean and standard deviation, for continuous variables, and frequency and percentages for categorical variables, were used to describe the characteristics of the sample and the resistance used in each exercise.

**2.5.1. Overall effect of exercise setup on muscle activation—**Linear mixed effects models were used to test the hypothesis that muscle activation differed between CC and OC exercises. This model was chosen to limit multiple comparisons and because it is robust regarding missing data points. In each model, EMG activation in mV was defined as the continuous response variable. Categorical model predictors were type of exercise (CC and OC) and muscle tested. The mixed effect term accounted for differences in response rate (random slope) and baseline activation (random intercept) between muscles across participants. Model comparison was performed using the Bayesian Inclusion Criteria and a log-likelihood test, which indicated that the random effect slope could be excluded from all models. To understand the effect of exercise type (CC vs OC) a main effect was calculated by muscle with activation collapsed across exercises. Alpha level was set at 0.05.

**2.5.2. Effect of exercise set up within each exercise and muscle—**Paired samples t-tests were used to compare the activation of each muscle during each pair of CC and OC exercise. Activation ratios were compared between exercise setup (CC vs OC) using a paired sample t-test. The alpha level was adjusted to 0.008 (0.05/6) using a Bonferroni correction for these analyses because average activation for each muscle and each ratio were compared between six matched pairs of exercises.

## 3. Results

### 3.1. Sample characteristics

Participants (n = 22) are described in Table 3 and the resistance used during the CC and OC exercises is reported in Appendix A and B, respectively. The average Q-DASH score of 3.1 suggests absence of functional limitations of the upper extremity. Further, participants were active as suggested by the average scores on the IPAQ questionnaire (3525 MET/min per week).

### 3.2. Primary analysis – overall effect of exercise setup on muscle activation

The SA muscle activity of two participants was removed from the analysis because the electrode detached from the skin. An electrode malfunction for the MT muscle was identified during processing of the OC latissimus pulldown for one participant, and for that trial the MT activation was removed from the analysis. When collapsed across exercises, the INF, LT, ES, and EO muscles had greater activation during the concentric phase of the CC compared to OC exercises ($p = 0.03$, Table 4). Further, INF, MT, LT, ES, and EO had greater activation during the eccentric phase of the CC compared to the OC exercises ($p < 0.01$, Table 4).

### 3.3. Secondary analysis – effect of exercise setup within each exercise and muscle

**3.3.1. Push up vs. horizontal press—**The CC push up generated higher activation of the SA (CC: 169.3 mV, OC: 119.1 mV; $p = 0.002$, Fig. 1) and EO (CC: 40.1 mV, OC: 13.7 mV; $p < 0.001$), but lower activation of the DEL (CC: 49.5 mV; OC: 67.0 mV; $p = 0.002$) and UT (CC: 43.3 mV, OC: 98.5 mV; $p < 0.001$) compared to the OC horizontal press. The CC push up generated lower DEL/INF ($p = 0.002$, Table 5), UT/MT ($p = 0.005$), UT/LT ($p < 0.001$), and UT/SA ($p = 0.001$) activation ratios compared to the OC press.

**3.3.2. Chin up vs. latissimus pulldown—**The CC chin up generated higher activation of the UT (CC: 29.9 mV, OC: 9.0 mV; $p < 0.001$), IN (CC: 81.9 mV, OC: 35.2 mV; $p < 0.001$), SA (CC: 29.6 mV, OC: 18.6 mV; $p = 0.001$), LT (CC:68.0 mV, OC: 44.2 mV; $p < 0.001$) and EO (CC: 23.3 mV, OC: 13.4 mV; $p = 0.004$), compared to the OC latissimus pulldown. The CC chin up generated greater UT/LT ($p = 0.001$), UT/MT ($p = 0.004$), and UT/SA ($p = 0.003$) activation ratios compared to the OC latissimus pulldown.

**3.3.3. Inverted row vs. horizontal row—**The CC inverted row generated higher activation of the INF (CC: 78.6 mV, OC: 50.7 mV; $p < 0.001$), SA (CC: 15.4 mV, OC: 8.4 mV; $p = 0.003$), MT (CC: 155.8 mV, OC: 111.3 mV; $p = 0.002$), LT (CC: 129.5 mV, OC: 70.3 mV; $p < 0.001$), and ES (CC: 40.3 mV, OC: 24.2 mV; $p < 0.001$) compared to the OC horizontal row. The CC inverted row generated lower DEL/INF ($p = 0.001$) activation ratio compared to the OC horizontal row.

**3.3.4. Triceps dips vs. triceps curls—**The CC triceps dips generated greater activation of the DEL (CC: 37.7 mV, OC: 29.2 mV; $p = 0.006$), UT (CC: 24.8 mV, OC: 12.1 mV; $p < 0.001$), INF (CC: 65.0 mV, OC: 29.8 mV; $p < 0.001$), SA (CC: 57.6 mV, OC: 22.0 mV; $p = 0.002$), MT (CC: 51.0 mV, OC: 24.1 mV; $p = 0.002$), ES (CC: 21.2 mV; OC:

11.0 mV; $p = 0.004$) compared to the OC triceps curls. The CC triceps dips generated lower DEL/INF ($p = 0.007$) activation ratio compared to the OC triceps curls.

#### 3.3.5. Shoulder depression

The CC shoulder depressions generated greater activation of the DEL (CC: 51.5 mV, OC: 21.6 mV; $p < 0.001$), UT (CC: 72.7 mV, OC: 35.8 mV; $p < 0.001$), INF (CC: 54.3 mV, OC: 21.0 mV; $p < 0.001$), SA (CC: 48.2 mV, OC: 23.8 mV; $p = 0.004$), MT (CC: 78.9 mV, OC: 28.3 mV; $p = 0.001$), ES (CC: 18.7 mV, OC: 6.2 mV; $p = 0.004$) compared to the OC shoulder depression. The CC shoulder depression generated lower UT/LT ($p = 0.001$) and UT/SA ($p = 0.007$) activation ratios compared to the OC setup.

#### 3.3.6. Vertical shoulder press

The CC vertical shoulder press generated lower activation of the DEL (CC: 90.9 mV, OC: 130.4 mV; $p = 0.004$), UT (CC: 136.1 mV, OC: 223.7 mV; $p = 0.001$), INF (CC: 46.0 mV, OC: 85.5 mV; $p < 0.001$) and MT (CC: 35.6 mV, OC: 58.1 mV; $p = 0.002$) compared to the OC vertical shoulder press. The CC shoulder press generated lower UT/SA activation ration ($p < 0.001$), but higher DEL/INF activation ration ($p = 0.002$) compared to the OC setup.

## 4. Discussion

In this study, the EMG activation of 6 shoulder and 2 trunk muscles was analyzed during CC and OC shoulder exercises under matched performance conditions. The results of the overall by muscle (activation collapsed across exercise), and independent (activation within each muscle and exercise) analyses partially support the first hypothesis: CC exercises elicited greater activation of shoulder (INF, MT, LT) and trunk (ES, EO) muscles compared to OC exercises. The second hypothesis was also partially supported by the results: overall CC exercises generated lower muscle activation ratios at the shoulder, but these results were not consistent across all CC exercises. The results for muscle activation and EMG ratios can inform clinicians for exercise selection and prescription. Further, previous studies are limited only to fit participants that are able to perform several CC repetitions against their body weight (De Mey et al., 2014; Fenwick et al., 2009; Ludewig et al., 2004; Maenhout et al., 2010; Muñoz-López et al., 2017; Youdas et al., 2010). In our study, the assistance of elastic bands allowed inclusion of participants that do not perform these types of exercises on a regular basis, making our results more generalizable. This CC setup may be advantageous to use with patients with shoulder disorders and pain.

### 4.1. Primary analysis – overall effect of exercise setup on muscle activation

Despite considering different exercises, the analysis of muscle activation collapsed across exercises indicated higher activation of the INF, MT (only in the eccentric phase), LT, ES and EO during CC exercises. These results indicate that CC exercises promote activation of the muscle responsible for providing stability of the of the scapulathoracic and glenohumeral joints, as well as the trunk. These results have important clinical applications because exercises that maximize activity of the rotator cuff and scapula stabilizers are recommended for patients with shoulder dysfunctions (Cools et al., 2007; Lin et al., 2005; Ludewig and Reynolds, 2009) and rotator cuff tears (Shinozaki et al., 2014). Lack of participant familiarity with novel CC exercises of the upper extremity may also be responsible for the increased muscle activity. However, during the first visit all participants practiced each CC and OC exercise, reducing the potential confounding effect of lack of familiarity with the exercises.

### 4.2. Secondary analysis – effect of exercise setup within each exercise and muscle

The CC push up generated greater activity in the SA compared to the OC horizontal press. The OC horizontal press required participants to keep their elbow at shoulder height (arm abducted to approximately 90°), which likely contributed to the high activation measured in the UT and DEL, compared to the CC push up. The lower activation of the UT in the CC push up may have contributed to the lower UT/LT, UT/MT, and UT/SA ratios measured in the CC push up compared to the OC horizontal press. The UT/SA ratio below 1 in the CC push indicates greater activity of the SA relative to the UT and corroborates with the findings of previous studies that analyzed EMG activity of the SA and UT during push up variations (standard, knee, elbow and wall push-up, ipsilateral leg extended or with unstable surfaces placed under the arms) (Ludewig et al., 2004; Maenhout et al., 2010). Other OC exercises that match the functional requirement of a CC push up, for example an OC bench press, may reduce the activation of the UT and DEL. However, the use of this type of CC setup in EMG studies may be not practical as laying supine may potentially alter the EMG signals of the electrodes placed on the back (MT, LT, and potentially INF). The UT/MT and UT/LT were significantly lower in the CC push up, but these ratios were above 1 in both the CC and OC setups. Maenhout et al. (2010) reported UT/MT and UT/LT ratios above 1 in healthy participants performing seven different push up exercise. Based on these findings, both the CC push up and OC horizontal press may not be effective at maximizing activity of the MT and LT relative to the UT.

EMG studies of chin up exercises have shown high activity of shoulder and back muscles (Muñoz-López et al., 2017; Youdas et al., 2010). Our findings indicated that the CC chin up generated greater activity of the UT, INF, SA, MT compared to an OC latissimus pulldown. Therefore, the CC chin up may be more effective as an upper body strengthening exercise compared to the OC latissimus pulldown. It should be noted that the UT/LT, UT/MT, and UT/SA ratio were greater in the CC chin up compared to the OC latissimus pulldown. Clinicians should consider these findings when selecting the CC chin up for patients with excessive shoulder hiking and provide supervision and instruction to avoid excessive scapular hiking when this exercise is used.

The CC inverted row, triceps dips, and shoulder depression are also optimal exercises to promote the activation of the INF, SA, MT, and LT, compared to the OC setup. The CC inverted row and triceps dips also promoted high activity of the INF relative to the DEL, as suggested by the low DEL/INF ratio. However, the CC inverted row and OC horizontal row should be avoided with patients with significant UT to SA activation imbalances, as the activation of the UT was approximately 9 times greater than the activation of the SA. High activation of the SA relative to the UT in a similar rowing exercise has been previously reported (De Mey et al., 2014). The position of the participants in both CC and OC set up may explain these findings. In the CC setup, participants were not completely parallel to the ground, and performed the CC inverted row at approximately a 45° angle. In the OC setup, the participant held the elbow at shoulder height (similar to the OC horizontal press). Other CC (i.e. inverted row parallel to the floor) and OC (i.e. standing row with shoulder in neutral position) rowing exercises may be more suitable for patients with significant scapular hiking.

Research on bilateral vertical shoulder press is limited. Our findings showed that the vertical shoulder press was the only exercise in which an OC setup generated higher activation than the CC setup. The CC setup required participants to lay on an exercise ball while performing a vertical shoulder press, thus challenging other aspects of motor control and reducing the ability of appropriately loading the shoulder. In terms of the activation ratios, both CC and OC setup generated greater activity of the UT relative to the LT and MT (ratios > 1), which may not be ideal in patients with shoulder dysfunction. Establishing the appropriate 5-repetition maximum resistance was also challenging on the CC set up. None of the participants could tension the thicker bands (blue and green, Appendix B) and the resistance offered by other bands may have been too light, especially for fit participants.

## 5. Limitations

The CC setup required the use of elastic bands to adjust the exercise load. The resistance (or assistance) varies during the movement and is greater when the band is maximally stretched. In contrast, the exercise load during the OC set up was constant throughout the motion due to the use of isotonic weights. This prevented exact matching of the exercise load between CC and OC setup. The resistance during the CC and OC setups was matched based on a self-reported 5 repetition maximum effort level. This is a potential limitation as participants may have under-estimated their effort level. The results of this study cannot be generalized to other type of CC and/or OC exercises of the upper extremity. Further, the results cannot be generalized to patient populations with shoulder disorders. Using surface EMG to study muscle activity during dynamic movements is also a limitation due to the potential movement of the muscle tissue underneath the EMG electrodes.

## 6. Conclusion

Overall, CC exercises of the upper extremity generated greater activation of shoulder and trunk muscles compared to OC. The CC push-up generated greater activity in the SA and the CC chin up, inverted row, triceps dips, and shoulder depression generated greater activity in the IN, SA, MT, and LT, compared to the OC exercises. The CC push up minimized the UT/SA ratio, the CC inverted row and triceps dips minimized the DEL/INF ratio, and the CC shoulder depression minimized the UT/MT ratio, compared to matched OC exercises. Caution should be used when selecting the CC chin up, CC inverted row, and OC horizontal row as they generated high activity of the UT relative to the MT and SA. The CC exercises setup used in this study allows for tailoring assistance (or resistance) to individual’s strength and ability to perform the exercise, which can potentially facilitate performance of CC exercises among unfit individuals and clinical populations.

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## Biography

**Federico Pozzi** is an Assistant Professor in the Department of Physical Therapy at the University of Florida. His research focuses on characterizing biomechanical, clinical, and functional impairments of patients with musculoskeletal shoulder pain to inform optimal physical therapy treatment and maximize patients' outcomes.

**Hillary Plummer** is an Associate Research Director with focus on biomechanics at the Andrews Research and Education Foundation. The focus of her research is to identify deficits in modifiable physical factors that prognosticate upper extremity injuries in overhead athletes.

**Natalia Sanchez** is an Assistant Professor of Research in the Division of Biokinesiology and Physical Therapy at the University of Southern California. Her research focuses on understanding the energetics of locomotion, the mechanisms of walking impairment in stroke and using statistical models applied to movement analyses.

**Yunae Lee** graduated with a Master in Biokinesiology from the Division of Biokinesiology and Physical Therapy at the University of Southern California. She is currently an Exercise Science Researcher at Under Armour and conducts R&D using biomechanics with a focus in athletic footwear.

**Lori Michener** is a Professor in the Division of Biokinesiology and Physical Therapy at the University of Southern California. The central theme of her funded research is to define optimal treatment pathways for patients with musculoskeletal shoulder disorders by focusing on characterizing mechanisms, defining classification and management approaches and determining optimal outcomes of care.

## Appendix A

**Table A1**

Isotonic weight (Kg) used for each open chain exercise. Data are presented as mean ± standard deviation (see Table A1).

| | |
|---|---|
| Horizontal press | 17.3 ± 8.1 |
| Latissimus pulldown | 29.7 ± 12.0 |
| Horizontal row | 19.2 ± 8.2 |
| Triceps curl | 16.2 ± 8.3 |
| Shoulder depression | 31.9 ± 15.1 |
| Vertical press | 14.1 ± 7.6 |

## Appendix B

### Table A2

Exercise assistance (or resistance) during closed chain exercise (see Table A2).

| | Elastic bands[a] | | | | | | | | | | | | | | No resistance (body weight) | Resistance (Kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Blue | | Green | | Purple | | Black | | Yellow | | Red | | Orange | | | | |
| | A | R | A | R | A | R | A | R | A | R | A | R | A | R | FREQ | FREQ | Mean ± SD |
| Push up | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 1 | 4 | 3 | 0 | 3 | 1 | 2 | 1 | 2[b] | 13.7 ± 6.4 |
| Chin up | 0 | | 9 | | 3 | | 0 | | 2 | | 1 | | 0 | | 3 | 4 | 13.1 ± 8.6 |
| Inverted row | 0 | | 0 | | 0 | | 0 | | 1 | | 2 | | 1 | | 3 | 15 | 8.8 ± 6.0 |
| Triceps dips | 0 | | 0 | | 0 | | 2 | | 5 | | 6 | | 0 | | 2 | 7 | 12.7 ± 11.4 |
| Shoulder depression | 0 | | 0 | | 0 | | 0 | | 4 | | 3 | | 0 | | 4 | 11 | 14.5 ± 11.5 |
| Vertical press | | 0 | | 0 | | 9 | | 3 | | 5 | | 5 | | 0 | | | |

Abbreviations: A, band used to provide assistance; R, band used to provide resistance; FREQ, frequency count; SD, standard deviation.

[a]Resistance increase from left to right. Blue higher assistance (or resistance); orange lowest resistance (or assistance). According to manufacturer data, the resistance of the thickest band (blue) is approximately 34 Kg at 10 cm length, and 95 Kg at 25 cm length; the resistance of the thinner band (orange) is approximately 2 Kg at 10 cm length, and 11 Kg at 25 cm length.

[b]One participant performed the push up using both the resistance from the blue band and one weight on the back.

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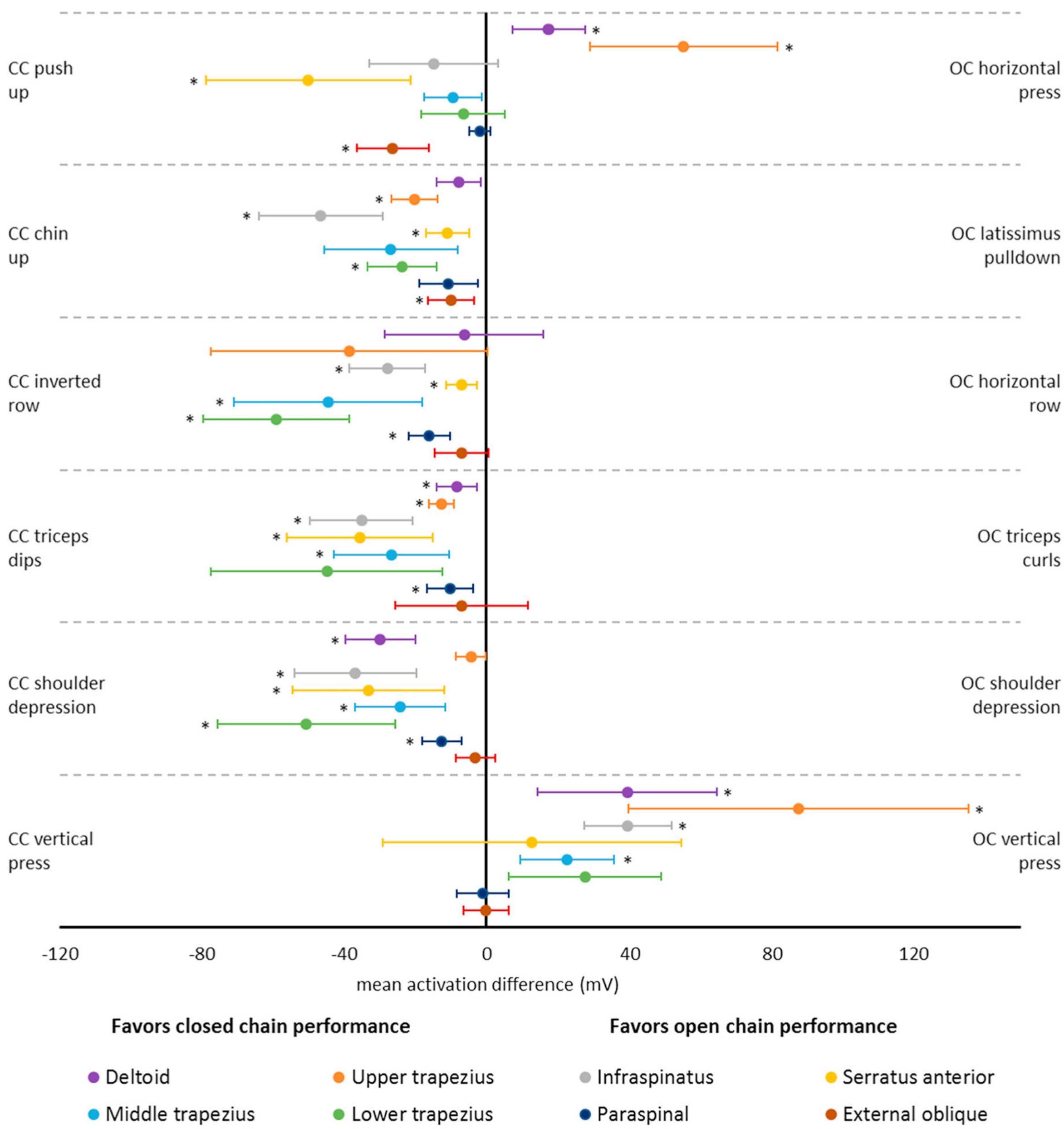



**Fig. 1.**

Mean activation differences between closed (CC) and open chain (OC) exercises. Solid circle represents mean activation in mV. Error bars represents 95% confidence interval. Mean differences were calculated as OC – CC, thus negative values indicate higher activation in CC performance. * Indicates significant difference activation between CC and OC for the specific muscle ($p < 0.008$).

**Table 1**

Closed and open chain exercises performed in this study. Participants executed the closed chain exercises at one of three levels: (1) assistance, exercise performed with an elastic band to offset body-weight; (2) no resistance, exercise performed against body weight; (3) resistance, exercise performed against participant body weight plus external resistance. During open chain exercises, participants performed each exercise against an isotonic weight set on the exercise machine. The level of performance on both closed and open chain exercises was based on each participant five repetition maximum.

## CLOSED CHAIN

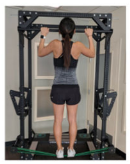
**Push Up**

**Instructions**

Lift the body from the ground until the elbow are fully extended

| | |
|---|---|
| **Concentric** | Lowest position to elbow fully extended |
| **Eccentric** | Elbow fully extended to lowest position |

| **Assistance** | **No Resistance** | **Resistance** |
|---|---|---|
| EB under the chest | BW | EB and/or IW on the back |



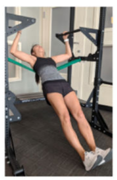
**Chin up**

**Instructions**

Pull the body up until the head pass the bar.

| | |
|---|---|
| **Concentric** | Lowest position to head passing the bar |
| **Eccentric** | Head above the bar to lowest position |

| **Assistance** | **No Resistance** | **Resistance** |
|---|---|---|
| EB under the feet | BW | IW around ankles |



**Inverted row**

**Instructions**

Pull the body up until the shoulder are in line with the elbow

| | |
|---|---|
| **Concentric** | Lowest position to shoulder and elbow aligned |
| **Eccentric** | Shoulder and elbow aligned to lowest position |

| **Assistance** | **No Resistance** | **Resistance** |
|---|---|---|
| EB under the feet | BW | IW on the chest |

**Triceps dips**

**Instructions**

Bend the elbow until ~ 90° and then extend them back to full extension

| | |
|---|---|
| **Concentric** | Elbow bent 90° to elbow fully extended |
| **Eccentric** | Elbow fully extended to elbow bent 90° |

| **Assistance** | **No Resistance** | **Resistance** |
|---|---|---|
| EB under the feet | BW | IW around ankles |

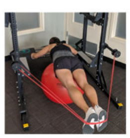
**Shoulder depression**

**Instructions**

Keeping your elbow straight, relax the shoulder (passive shrug), and then depress your shoulder as much as possible

| | |
|---|---|
| **Concentric** | Shoulder fully relaxed to maximum depression |
| **Eccentric** | Maximum depression to shoulder fully relaxed |

| **Assistance** | **No Resistance** | **Resistance** |
|---|---|---|
| EB under the feet | BW | IW around ankles |



**Vertical press**

**Instructions**

Lay on the exercise ball, place your hand on the step and push your body away from the platform by straightening your elbow

| | |
|---|---|
| **Concentric** | Body close to the platform to elbow fully extended |
| **Eccentric** | Elbow fully extended to body close to the platform |

**Resistance**

EB under the feet

## OPEN CHAIN

**Horizontal press**

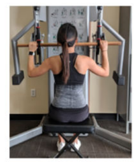
**Instructions**

Push the bar away from the body until elbows are fully extend

| | |
|---|---|
| **Concentric** | Bar close to the body to elbow fully extended |
| **Eccentric** | Elbow fully extended to bar close to the body |

**Resistance**

IW



**Latissimus pulldown**

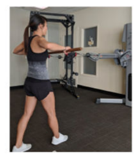
**Instructions**

Pull the bar down below your head

| | |
|---|---|
| **Concentric** | Elbow fully extended to bar down below the head |
| **Eccentric** | Bar below the head to elbow fully extended |

**Resistance**

IW



**Horizontal row**

**Instructions**

Keep the elbow at shoulder level and pull the bar toward the body

| | |
|---|---|
| **Concentric** | Bar away from the body to bar close to the body |
| **Eccentric** | Bar close to the body to bar away from the body |

**Resistance**

IW

**Triceps curls**

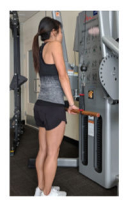
**Instructions**

Bend the elbow until ~ 90° and then extend them back to full extension

| | |
|---|---|
| **Concentric** | Elbow bent 90° to elbow fully extended |
| **Eccentric** | Elbow fully extended to elbow bent 90° |

**Resistance**

IW



**Shoulder depression**

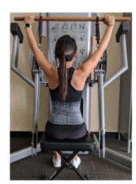
**Instructions**

Keeping your elbow straight, relax the shoulder (bar up), and then depress your shoulder as much as possible

| | |
|---|---|
| **Concentric** | Shoulder fully relaxed to maximum depression |
| **Eccentric** | Maximum depression to shoulder fully relaxed |

**Resistance**

IW



**Vertical press**

**Instructions**

Push the bar vertically away from the body until the elbow are fully extended

| | |
|---|---|
| **Concentric** | Bar at nose level to elbow fully extended |
| **Eccentric** | Elbow fully extended to bar at nose level |

**Resistance**

IW

Abbreviations: EB, elastic band; BW, body weight; IW, isotonic weight.

**Table 2**

Electromyography electrode positions for the muscles analyzed in this study.

| Muscle | Electrodes position |
|---|---|
| Deltoid | Mid-distance between the acromion and the humeral tuberosity (Hermens et al., 2000) |
| Upper trapezius | Halfway on the line from the acromion to C7 (Hermens et al., 2000) |
| Infraspinatus | Halfway and 2 cm below the scapula spine (Allen et al., 2013) |
| Serratus anterior | On the lateral border of the chest anterior to the latissimus dorsi and posterior to the pectoralis major (Maenhout et al., 2010) |
| Middle trapezius | At T3 level between the medial border of the scapula and the spine (Hermens et al., 2000) |
| Lower trapezius | At 2/3 on the line from the scapula spine to T8 (Hermens et al., 2000) |
| Erector spinae | Approximately 3 cm lateral to the spinous process at L3 level (Fenwick et al., 2009) |
| External oblique | Approximately 3 cm lateral to the linea semi lunaris (Fenwick et al., 2009) |
| Reference | Spinous process of C7 |

**Table 3**

Demographic characteristics of the participants (N = 22). Values are presented as mean ± standard deviation unless otherwise indicated.

| | |
|---|---|
| Sex, male n (%) | 11 (50%) |
| Age, years | 26.3 ± 4.3 |
| Height, m | 1.7 ± 0.1 |
| Weight, kg | 64.5 ± 14.1 |
| BMI, kg/m$^2$ | 22.3 ± 2.9 |
| Q-DASH, % | 3.1 ± 4.4 |
| IPAQ short form | |
| MET-minute per week | 3525 ± 2432.5 |
| High physical activity, n (%) | 10 (45) |
| Moderate physical activity, n (%) | 9 (41) |
| Low physical activity, n (%) | 3 (14) |

Abbreviations: BMI, body mass index; Q-DASH, Quick Disability of the Arm and Shoulder scale; IPAQ, International Physical Activity Questionnaire; MET, Metabolic Equivalent.

## Table 4

Electromyography activation during the closed and open chain exercises. Values are reported in mV.

| | Unadjusted raw scores[a] | | Adjusted scores[b] | | | |
|---|---|---|---|---|---|---|
| | Open chain | Closed chain | Open chain | Closed chain | Mean difference[c] | p-value |
| **Concentric phase** | | | | | | |
| Main effect of exercise type collapsed across exercises | | | | | | |
| Deltoid | 79.9 ± 27.2 | 76.7 ± 17.9 | 79.9 ± 27.2 | 76.7 ± 17.9 | 5.8 (−12.7, 24.3) | 0.54 |
| Upper trapezius | 99.2 ± 46.5 | 87.8 ± 33.9 | 99.2 ± 46.5 | 87.8 ± 33.9 | 19.2 (−15.4, 53.9) | 0.27 |
| Infraspinatus | 60.4 ± 11.3 | 82.3 ± 5.7 | 60.4 ± 11.3 | 82.3 ± 5.7 | −15.2 (−26.7, −3.6) | 0.01[d] |
| Serratus anterior | 78.9 ± 37.1 | 98.9 ± 31.2 | 76.2 ± 36.3 | 97.4 ± 34.4 | −24.6 (−61.7, 12.6) | 0.19 |
| Middle trapezius | 59.9 ± 19.4 | 80.1 ± 23.8 | 60.0 ± 19.3 | 80.1 ± 23.8 | −16.0 (−36.3, 4.4) | 0.12 |
| Lower trapezius | 64.0 ± 12.3 | 94.2 ± 13.6 | 64.0 ± 12.3 | 94.2 ± 13.6 | −30.5 (−49.2, −11.8) | < 0.01[d] |
| Paraspinal | 14.7 ± 3.1 | 23.6 ± 4.9 | 14.7 ± 3.1 | 23.6 ± 4.9 | −8.5 (−15.0, −1.9) | 0.01[d] |
| External oblique | 16.0 ± 1.3 | 25.2 ± 4.6 | 16.0 ± 1.3 | 25.2 ± 4.6 | −8.8 (−16.9, −0.7) | 0.03[d] |
| **Eccentric phase** | | | | | | |
| Main effect of exercise type collapsed across exercises | | | | | | |
| Deltoid | 41.2 ± 11.6 | 42.9 ± 8.8 | 41.2 ± 11.6 | 42.9 ± 8.8 | −1.7 (−9.9, 6.6) | 0.69 |
| Upper trapezius | 57.8 ± 22.4 | 46.9 ± 13.7 | 57.8 ± 22.4 | 46.9 ± 13.7 | 10.9 (−3.6, 25.4) | 0.14 |
| Infraspinatus | 38.7 ± 5.9 | 57.5 ± 5.3 | 38.7 ± 5.9 | 57.5 ± 5.3 | −18.8 (−26.2, −11.4) | < 0.01[d] |
| Serratus anterior | 49.1 ± 25.2 | 68.0 ± 23.3 | 47.8 ± 24.9 | 67.1 ± 23.4 | −20.3 (−42.2, 1.6) | 0.07 |
| Middle trapezius | 35.8 ± 8.2 | 51.8 ± 13.6 | 35.1 ± 8.3 | 51.8 ± 13.6 | −16.8 (−24.1, −6.5) | < 0.01[d] |
| Lower trapezius | 40.9 ± 6.8 | 63.2 ± 9.9 | 40.9 ± 6.8 | 63.2 ± 9.9 | −22.3 (−33.9, 10.7) | < 0.01[d] |
| Paraspinal | 10.3 ± 2.6 | 18.9 ± 3.5 | 10.3 ± 2.6 | 18.9 ± 3.5 | −8.6 (−13.2, −4.1) | < 0.01[d] |
| External oblique | 10.5 ± 0.5 | 19.2 ± 3.5 | 10.5 ± 0.5 | 19.2 ± 3.5 | −8.8 (−14.4, −3.2) | < 0.01[d] |

[a] Values are mean ± standard error.

[b] Adjusted scores from the general linear mixed model. Values are mean ± standard error.

[c] Calculation of the adjusted mean difference included a random effect term for each subject. Difference calculated as open chain – closed chain.

[d] Significantly different ($p < 0.05$).

## Table 5

Functional activation ratios for open and closed chain exercise setup. Activation used in the calculation of muscle ratios was normalized to the maximal activation during a maximal voluntary isometric contraction.

| | Open chain[a] | Closed chain[a] | Mean difference[b] | p value |
|---|---|---|---|---|
| Push up/horizontal press | | | | |
| DEL/INF | 0.70 ± 0.09 | 0.46 ± 0.06 | 0.24 (0.09; 0.39) | 0.002[c] |
| UT/LT | 2.11 ± 0.45 | 1.04 ± 0.25 | 1.07 (0.34; 1.81) | 0.005[c] |
| UT/MT | 2.75 ± 0.45 | 1.17 ± 0.21 | 1.58 (0.98; 2.17) | < 0.001[c] |
| UT/SA | 0.58 ± 0.07 | 0.21 ± 0.04 | 0.37 (0.26; 2.48) | < 0.001[c] |
| Chin up/latissimus pulldown | | | | |
| DEL/INF | 0.28 ± 0.07 | 0.18 ± 0.02 | 0.11 (−0.01; 0.22) | 0.042 |
| UT/LT | 0.18 ± 0.44 | 0.31 ± 0.05 | −0.13 (−0.20; −0.06) | 0.001[c] |
| UT/MT | 0.23 ± 0.04 | 0.35 ± 0.06 | −0.13 (−0.22; −0.05) | 0.004[c] |
| UT/SA | 0.39 ± 0.08 | 0.90 ± 0.21 | −0.51 (−0.82; −0.19) | 0.003[c] |
| Inverted row/horizontal row | | | | |
| DEL/INF | 1.12 ± 0.12 | 0.79 ± 0.11 | 0.33 (0.15; 0.52) | 0.001[c] |
| UT/LT | 0.80 ±0.11 | 0.63 ± 0.08 | 0.17 (0.01; 0.33) | 0.024 |
| UT/MT | 0.69 ± 0.07 | 0.72 ± 0.09 | −0.03 (−0.22; 0.17) | 0.392 |
| UT/SA | 9.96 ± 2.26 | 9.29 ± 2.42 | 0.67 (−3.06; 4.40) | 0.365 |
| Triceps dips/triceps curls | | | | |
| DEL/INF | 0.57 ± 0.08 | 0.38 ± 0.06 | 0.19 (0.05; 0.33) | 0.007[c] |
| UT/LT | 0.26 ± 0.06 | 0.21 ± 0.04 | 0.05 (−0.04; 0.14) | 0.154 |
| UT/MT | 0.56 ± 0.15 | 0.52 ± 0.11 | 0.07 (−0.11; 0.25) | 0.240 |
| UT/SA | 0.53 ± 0.13 | 0.41 ± 0.08 | 0.12 (−0.06; 0.29) | 0.107 |
| Shoulder depression | | | | |
| DEL/INF | 0.37 ± 0.06 | 0.47 ± 0.06 | −0.09 (−0.23; 0.04) | 0.092 |
| UT/LT | 0.68 ±0.15 | 0.25 ± 0.04 | 0.43 (0.19; 0.68) | 0.001[c] |
| UT/MT | 0.81 ± 0.14 | 0.67 ± 0.20 | 0.14 (−0.16; 0.45) | 0.185 |
| UT/SA | 1.09 ± 0.28 | 0.43 ± 0.08 | 0.66 (0.18; 1.14) | 0.007[c] |
| Vertical shoulder press | | | | |
| DEL/INF | 0.88 ± 0.09 | 1.22 ± 0.14 | −0.34 (−0.53; −0.14) | 0.002[c] |
| UT/LT | 1.47 ± 0.12 | 1.38 ± 0.23 | 0.10 (−0.30; 0.49) | 0.317 |
| UT/MT | 2.85 ± 0.40 | 3.43 ± 0.73 | −0.58 (−1.70; 0.54) | 0.161 |
| UT/SA | 0.95 ± 0.15 | 0.57 ± 0.10 | 0.37 (0.21; 0.54) | < 0.001[c] |

Abbreviation: DEL, deltoid; INF, infraspinatus; UT, upper trapezius; MT, middle trapezius; LT, lower trapezius; SA, serratus anterior.

[a]Ratio > than 1 indicate higher activation in the deltoid or upper trapezius. Reported as mean ± standard error.

[b]Calculated as open chain – closed chain. Positive values indicate higher ratio in open chain setup. Reported as mean (95% confidence interval).

[c]significantly different ($p < 0.008$).