International Journal of Strength and Conditioning

Gomes, W. A., da Silva, J. J., Magalhaes, R. A., Teixeira, L. F. M., Paulino, R. C., & Marchetti, P. H. (2025). Comparison of Peak Force and Myoelectric Activity of the Anterior and Middle Deltoid at Three Shoulder Angles During Frontal, Diagonal, and Lateral Raise Exercises in Trained Men. International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v5i1.522

# Comparison of Peak Force and Myoelectric Activity of the Anterior and Middle Deltoid at Three Shoulder Angles During Frontal, Diagonal, and Lateral Raise Exercises in Trained Men

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## ABSTRACT

The objective of the present study was to compare the peak force and myoelectric activity of the anterior (AD) and middle deltoid (MD) at three different shoulder joint angles during the frontal (FR), diagonal (DR), and lateral raise (LR) exercises in recreationally-trained men. Fifteen resistance-trained men (age: 27±5 years, height: 173±9 cm, total body mass: 81±10 kg) were assigned to this study. Three resistance exercises (FR, DR, and LR) were tested isometrically at three different shoulder joint angles (0°, 45°, and 90°). Peak force (PF) and myoelectric activity (iEMG) were measured for all exercises and shoulder joint angles. A two-way repeated-measures ANOVA (3x3) was used to test differences between exercises (FR, DR, and LR) and shoulder joint angles (0°, 45°, and 90°) for PF. A three-way repeated-measures ANOVA (2x3x3) was used to test differences between muscle groups (AD and MD), exercises (LR, DR, and FR), and shoulder joint angles (0°, 45°, and 90°) for iEMG. All RT exercises presented similar levels of force production and myoelectric activity (AD and MD) regardless of the specific plane of motion ($p>0.05$). However, the shoulder joint position affected the force production and AD activity without changes for MD.


Keywords: shoulder position, isometric strength, and muscle activity.

## INTRODUCTION

Exercise selection is an important aspect of a resistance training (RT) program aiming for strength, power, or hypertrophy [1]. The exercise selection is based on the specificity of the movement, considering factors such as the number of joints involved, plane of motion, prime movers, and stabilizers, as well as the influence of this exercise in different RT routines, frequency, and periodization phase [1] Specifically, the shoulder joint allows for a wide range of movements due to its multiplanar nature. Therefore, each possible joint movement is expected to occur in a specific plane and directly influence the participation of the surrounding muscles [2-6]. The frontal raise (FR) and lateral raise (LR) are RT exercises commonly used to target different portions of the deltoid muscle, such as the anterior deltoid (AD) and middle deltoid (MD). Carotella et al. [3] examined the myoelectric activation of the AD and MD during the FR exercise and LR exercise with the humerus in different shounder rotations (external, neutral, and internal) in ten bodybuilders. The authors observed that the AD showed greater myoelectric activity during the FR and LR in internal rotation. The MD exhibited greater myoelectric activity during the LR in neutral rotation compared to the LR in external rotation and the FR exercise. Bagchi and Raizada [7] compared the myoelectric activation of the AD during the FR exercise with different radioulnar joint positions (pronated, supinated, and neutral). Their findings indicated greater AD activity during the FR in a pronated radioulnar position. Thus, changes in the plane of movement or shoulder position appear to affect the participation of different portions of the deltoid.

The diagonal raise (DR) is a widely used RT exercise that involves movement in the scapular plane, characterized by an angle of approximately 30 to 45 degrees in front of the body and aligned with the scapulae [2, 8-11]. The DR is commonly performed in both strength training and rehabilitation programs because it provides greater joint stability. Additionally, it is considered a more natural position for the shoulder joint, as the acromion allows more space for the tendons, reducing friction and the risk of inflammation [10]. However, information on the muscular activity of the deltoid portions and force production is scarce in the scientific literature, especially when movements in intermediate planes (diagonals) are performed. Additionally, understanding muscular function at different joint angles, without the effects of angular velocity, is fundamental for the proper prescription of isometric training for strength training practitioners and patients in rehabilitation. Therefore, this study aimed to compare the peak force and myoelectric activity of the anterior and middle deltoid at three different shoulder joint angles during the frontal, diagonal, and lateral raise exercises in recreationally-trained men. The main hypotheses were that 1. similar levels of PF are observed between RT exercises for each specific shoulder joint angle, 2. increasing shoulder joint angle does not affect PF for all RT exercises, 3. AD and MD activity increases with increasing shoulder joint angle among RT exercises, and 4. AD and MD activity is not affected by different RT exercises for the same shoulder joint angle.

## METHODS

### *Participants*

The number of participants (n=15) was determined using a previously conducted pilot study with individuals with similar characteristics as this study, based on a significance level of 5% and a test power of 80%[12]. Fifteen resistance-trained men (age: 27±5 years, height: 173±9 cm, total body mass: 81±10 kg) were assigned to this study. Participants had 7±3 years of resistance training experience (at least 3 times a week) and were familiar with lateral raise, diagonal raise, and frontal raise exercises. Participants had no previous surgery or history of injury with residual symptoms (pain) in the upper limbs or spine within the last year. The participants were informed of the risks and benefits of the study prior to any data collection and then read and signed an institutionally informed consent document approved by the Institutional Review Board at the University (protocol no. 6.003.773).

### *Procedures*

This study used a randomized and counterbalanced design. The participants attended one session in the laboratory and refrained from performing any upper body exercises other than daily activities for at least 72 hours prior to testing. All participants were asked to identify their preferred arm for writing, which was considered their dominant arm[13]. Next, all participants performed a familiarization, and a specific warm-up was performed for all exercises with 1 set of 15 repetitions without external load and 5-min between exercises. Then, the participants performed three exercises (frontal, diagonal, and lateral raise) in maximal voluntary isometric contraction (MVIC) at three different shoulder joint angles (0°, 45°, and 90°) (Figure 1). All participants remained standing with the torso in the vertical position, their elbows extended, wrists in a neutral position, and pronated handgrip holding a handle connected to a cross-over equipment. The cross-over equipment was adjusted to maintain the cable perpendicular to the participant's upper limb. For the lateral raise exercise (LR), the shoulder joint was abducted and internally rotated; for the diagonal raise (DR) exercise, the shoulder joint was horizontally abducted at 30° (scapular plane)[14] and internally rotated; and for the frontal raise (FR),

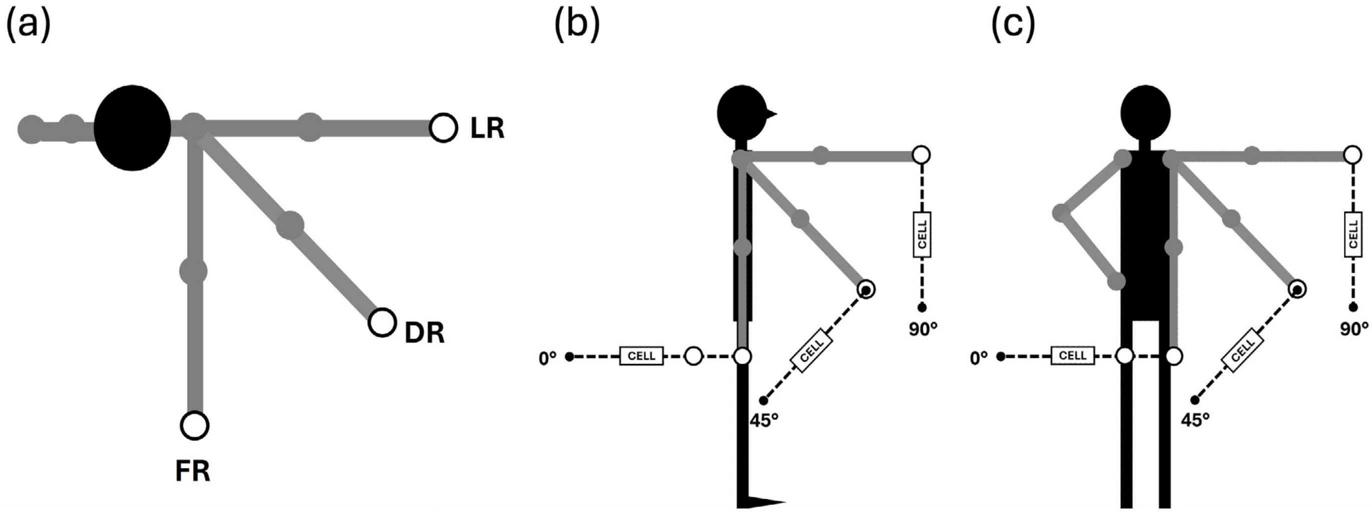


**Figure 1.** Shoulder joint positions: (a) Superior view of all RT exercises, (b) shoulder joint angles for FR and load cell position, and (c) shoulder joint angles for LR and load cell position.

the shoulder joint was flexed and internally rotated. All exercises (FR, DR, and LR) and shoulder joint positions (0°, 45°, and 90°) were randomized for each participant. All participants received verbal encouragement during all RT exercises and angles, and all measurements were performed at the same hour of the day (between 9 and 12 AM) by the same researcher.

### *Measurements*

*Shoulder Joint Position:* A fleximeter (model FL6010, Sanny, SP, Brazil) was used to control the shoulder joint position (0°, 45°, and 90°) in all exercises (FR, DR, and LR). The zero degree was defined when the upper limb was aligned vertically. The fleximeter was positioned on the dominant upper limb.

*Maximal Voluntary Isometric Contraction (MVIC):* The MVIC was measured by a load cell acquisition system (EMG832C, EMG system, São José dos Campos, Brazil) with a sampling rate of 2KHz using a commercially designed software program (EMG system, São José dos Campos, Brazil). In order to acquire MVIC, a load cell was fixed between the handle and the cross-over equipment. During all exercises and shoulder joint angles, the load cell was adjusted to remain perpendicular to each participant's upper limb. All participants performed 3 maximal voluntary isometric contractions (MVIC) for each exercise and shoulder joint angle. Each MVIC was performed for 5-sec and 10-sec rest intervals. A ten-minute rest was given after each RT exercise and tested shoulder angle position. The digitized data were low-pass filtered at 10 Hz using a fourth-order Butterworth filter with a zero lag. The peak force (PF) of each MVIC was defined and the average of the 3 MVICs was used for further analysis. The reliability (ICC) of PF data ranged between 0.95 and 0.98. All MVIC data were synchronized with the myoelectric activation of AD and MD.

*Myoelectric Activity (sEMG):* The participants' skin was prepared before the placement of the sEMG electrodes. Hair at the site of electrode placement was shaved, and the skin was cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl snap electrodes were used, which were 1 cm in diameter for each circular conductive area with 2-cm center-to-center spacing. The specific location of each electrode was guided according to SENIAM recommendations [16]. For the anterior deltoid (AD), the electrodes were positioned one finger width distal and anterior to the acromion. For the middle deltoid (MD), the electrodes were positioned from the acromion to the lateral epicondyle of the elbow, corresponding to the muscle's largest protrusion. The sEMG signals were recorded by an electromyography acquisition system (EMG832C, EMG system, São Jose dos Campos, Brazil) with a sampling rate of 2KHz using a commercially designed software program (EMG system, Brazil). EMG amplitude was amplified (bipolar differential amplifier, input impedance = 2 MΩ, common-mode rejection ratio >100 dB min (60 Hz), gain x 20, noise > 5 μV) and analog-to-digitally converted (12 bit). The ground electrode was placed on the bony prominence of the elbow (olecranon). All sEMG data were analyzed with a software program (EMG system, São José dos Campos, Brazil). The digitized sEMG data were band-pass filtered at 20-400 Hz using a fourth-order Butterworth filter with a zero lag. For myoelectric activation timedomain analysis, RMS (150ms moving window) was calculated during each MVIC. The area under the RMS sEMG curve was calculated, defining the integrated sEMG (iEMG). The reliability (ICC) of the iEMG data between isometric contractions ranged between 0.68 and 0.83.

### *Statistical Analysis*

The normality and homogeneity of variances were confirmed by the Shapiro-Wilk and Levene's tests, respectively. Mean, standard deviation, effect size (d), delta percentage (Δ%), and 95% confidence interval (CI95%) were calculated. A two-way repeated-measures ANOVA (3x3) was used to test differences between exercises (FR, DR, and LR) and shoulder joint angles (0°, 45°, and 90°) for PF. A three-way repeated-measures ANOVA (2x3x3) was used to test differences between muscle groups (AD and MD), exercises (LR, DR, and FR), and shoulder joint angles (0°, 45°, and 90°) for iEMG. Post-hoc comparisons were performed with the Bonferroni test when necessary. Cohen's formula (d) was qualitatively interpreted using the following criteria: <0.50 trivial effect; 0.50 - 1.25 small effect; 1.25 - 1.90 moderate effect; and >2 large effect for trained participants [15]. A significance level (α) of 5% was used for all statistical tests using SPSS software version 21.0.

## RESULTS

For PF (Figure 2a and Table 1), main effects were observed for exercise ($p$=0.001) and shoulder joint angle ($p$=0.001). There was interaction between exercise and shoulder joint angle ($p$=0.015).

For iEMG, main effects were observed main effects for muscle group ($p$<0.001) and shoulder joint angle ($p$=0.001). There were interactions between muscle group x exercise ($p$<0.001) and muscle group x shoulder joint angle ($p$<0.001) (Figure 2b and 2c, and Table 2).

**Table 1.** Comparison of peak force between exercises and shoulder joint angle (*p*-value, delta percentage [Δ%], and 95% confidence interval [$CI_{95\%}$]) for anterior deltoid (iEMG).

| Comparison | *p*-value | Δ% | Effect Size |
|---|---|---|---|
| FR0 x FR90 | 0.008 | 17% | 0.64 [small effect] |
| DR0 x DR45 | 0.009 | 16% | 1.43 [moderate effect] |
| DR0 x DR90 | 0.002 | 21% | 1.84 [moderate effect] |
| LR0 x LR45 | 0.001 | 26% | 2.25 [large effect] |
| LR0 x LR90 | 0.001 | 27% | 2.79 [large effect] |
| FR0 x LR0 | 0.007 | 15% | 1.28 [moderate effect] |

**Table 2.** Comparison of iEMG between muscle groups, exercises, and shoulder joint angle (*p*-value, delta percentage [Δ%], and 95% confidence interval [$CI_{95\%}$]) for anterior deltoid and middle deltoid.

| Comparison | *p*-value | Δ% | Effect Size |
|---|---|---|---|
| Anterior Deltoid | | | |
| FR0 x FR90 | 0.05 | 37% | 0.52 [small effect] |
| DR0 x DR90 | 0.001 | 66% | 0.60 [small effect] |
| LR0 x LR45 | 0.018 | 51% | 0.67 [small effect] |
| LR0 x LR90 | 0.002 | 61% | 0.74 [small effect] |
| Middle Deltoid | | | |
| LR0 x LR90 | 0.041 | 30% | 0.51 [small effect] |
| FR90 x LR90 | 0.001 | 25% | 0.52 [small effect] |
| Anterior Deltoid x Middle Deltoid | | | |
| DR90 | 0.007 | 40% | 0.67 [small effect] |
| FR0 | 0.020 | 52% | 0.55 [small effect] |
| FR45 | 0.029 | 39% | 0.60 [small effect] |
| FR90 | 0.001 | 52% | 0.76 [small effect] |

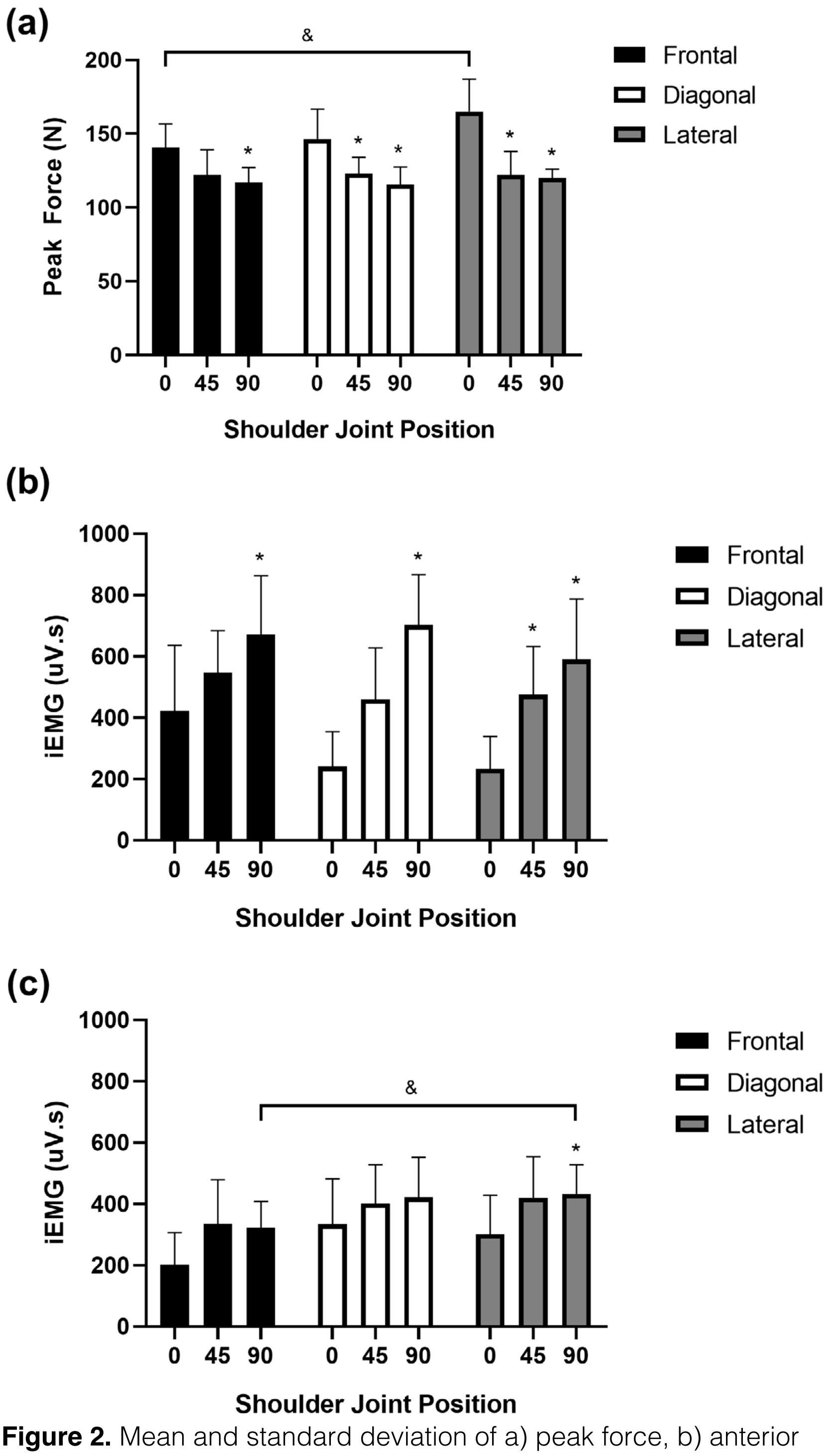


**Figure 2.** Mean and standard deviation of a) peak force, b) anterior deltoid for exercises (DR, LR, and FR) and shoulder joint angles (0°, 45°, and 90°), and c) medial deltoid for different exercises (DR, LR, and FR) and shoulder joint angles (0°, 45°, and 90°). *Significant difference with 0°. &Significant difference between exercises.

## DISCUSSION

The objective of the present study was to compare the peak force and myoelectric activity of the anterior and middle deltoid at three different shoulder joint angles during the frontal, diagonal, and lateral raise exercises in recreationally-trained men. The main findings of this study are 1. a reduction in PF with increasing shoulder joint angle in all RT exercises (0°>45°>90°), 2. a similar PF pattern was observed among RT exercises, 3. an increased AD activity with increased shoulder joint angles in all RT exercises (0°<45°<90°), 4. a similar AD activity among RT exercises for each shoulder joint angle, 5. an increased MD activity with increased shoulder joint angles only for the LR exercise (0°<90°), 6. the AD activity was higher than MD for FR [0° (52%), 45° (39%), and 90°(52%)], and DR [90°(40%)].

The peak force (PF) was measured during all RT exercises and shoulder joint angles. The objective of this measurement was to evaluate the level of isometric maximal force across all RT exercises and shoulder joint angles. This information is essential for understanding the physical stress imposed by different RT exercises and joint positions. The hypothesis was that similar levels of PF would be observed between RT exercises for each specific shoulder joint angle; however, this hypothesis was corroborated in the present study. All RT exercises presented similar PF values when compared by shoulder joint angle, with the exception of the highest PF between the FR and LR exercises at 0° (LR>FR, 15%). Regarding the effects of each shoulder joint position, the present study evaluated PF using a load cell always perpendicular to the subjects' arm. That said, the hypothesis was that increasing the shoulder joint angle would not affect PF for all RT exercises. This hypothesis was partially corroborated in the present study. All RT exercises presented reduction in PF with increasing of the shoulder joint angle (0°>45°>90°). Therefore, the reduction in peak force (PF) with increasing shoulder joint angle may be partially attributed to suboptimal length–tension relationships of the prime movers or it is possible that muscles such as the pectoralis major might have contributed more substantially at smaller shoulder joint angles, thereby enhancing force production only in those positions.

During the assessment of PF in all RT exercises and shoulder joint angles, the myoelectric activity (iEMG) of AD and MD portions were also assessed. The hypothesis was that AD activity would increase with increasing of the shoulder joint angle in all RT exercises. This hypothesis was corroborated by the results presented in this study. In fact, there was an increase in AD activity between 0° and 90° for all RT exercises (between 37 to 66%). The difference observed in shoulder joint angles might be attributed to the specific characteristics of the length–tension relationship in the deltoid muscle. It is possible that variations in muscle length at different joint positions influenced the capacity for force generation, thereby affecting joint angle outcomes [6, 9-11]. At lower joint angles (0°), muscle activity was lower, possibly due to the greater length of the muscle fibers.

The opposite condition occurred at higher joint angles (90°). Additionaly, it is plausible that changes in the shoulder plane of motion could affect muscle engagement. Therefore, the hypothesis was that AD activity would not be affected by different RT exercises for the same shoulder joint angle, however the results of the present study corroborated this hypothesis. The AD activity was similar among RT exercises for the same shoulder joint angle. Contrary to the findings of the present study, Carotella et al., (2020)[3] reported greater AD activity during FR when compared to LR exercise. However, the study evaluated muscle activity in dynamic actions (concentric and eccentric) and not in specific shoulder joint angles.

Finally, MD is another key muscle portion that may be influenced by both the plane of motion and the shoulder joint angle. It is plausible that changes in these biomechanical factors alter its myoelectric activation or force production [6, 9-11]. Therefore, the hypothesis was that MD activity would increase with increasing of the shoulder joint angle for all RT exercises. However, this hypothesis was not corroborated by the results presented in this study, with just one exception for the FR exercise (0°<90°). Then, the next hypothesis considered that changes in the shoulder plane of motion would not affect muscle engagement between RT exercises for the same shoulder joint angle. The results of the present study corroborated this hypothesis. In fact, the authors observed a difference in muscle action only between FR and LR at 90° (LR>FR, 25% difference). Therefore, it was observed that the MD was not substantially influenced by the joint angle or exercise analyzed. Carotella et al., (2020)[3] reported greater MD activity during LR when compared to FR exercise in dynamic actions (concentric and eccentric) and not in specific shoulder joint angles.

It is worth noting that in order to adequately understand the muscular activity of both muscles analyzed in the present study, it must be taken into consideration that the external load was applied perpendicularly to the subjects' arm in all exercises and joint angles, which makes comparison with other studies difficult.

This study has some limitations that should be considered when interpreting the current results. First, despite this limitation in the sample size, the analysis of effect sizes provides a good basis for drawing inferential conclusions from the results. Second, only isometric actions were evaluated and cannot be generalized to dynamic conditions. Third, this study analyzed two portions (AD and MD) of the deltoid muscle group. Fourth, the present data were not normalized by maximal isometric voluntary contractions, however, the lack of normalization was not an omission but an intentional choice, considering that all EMG data were measured in maximal isometric conditions [16]. Fifth, Short rest intervals between maximal isometric contractions may not be sufficient to completely remove neuromuscular fatigue, however, the pilot study carried out in our laboratory (using a frequency domain EMG analysis) showed that a 10-second interval was deemed sufficient to eliminate residual neuromuscular fatigue from a 5-second maximal isometric contraction in trained subjects. This conclusion was supported by the high reliability range observed in our peak force (PF) data (between 0.95 and 0.98). Finaly, the study only presented acute muscular responses that cannot be directly related to chronic adaptations such as hypertrophy. The findings of this study are specific to young resistance-trained men and therefore cannot necessarily be generalized to other muscle groups, different populations.

## CONCLUSION

It is concluded that all RT exercises analyzed presented similar levels of force production and myoelectric activity (AD and MD) regardless of the specific plane of motion. However, the shoulder joint position affected the force production and AD activity without changes for MD.

## CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest with the content of the manuscript.

## FUNDING

No funding was received in order for this research to be completed.

## ETHICAL APPROVAL

The participants were informed of the risks and benefits of the study prior to any data collection and then read and signed an institutionally informed consent document approved by the Institutional Review Board at the University (protocol no. 6.003.773).

## DATES OF REFERENCE

Submission - 02/03/2025
Acceptance - 15/07/2025
Publication - 21/11/2025

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