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Effects of scapular retraction/protraction position and scapular elevation on shoulder girdle muscle activity during glenohumeral abduction☆

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ABSTRACT

According to scapulohumeral rhythm, shoulder abduction is followed through scapular upward rotation to ensure joint mobility and stability. Of interest, the shoulder abduction can be performed holding the scapula in different positions and in association with scapular elevation, with possible effects on shoulder muscle activity. Therefore, the aim of the study was to analyze the activity of relevant shoulder muscles and the activity ratios between the scapulothoracic muscles, during shoulder abduction performed in different combinations of scapular position (neutral, retracted, protracted) and scapular elevation.

The electromyographic activity of middle deltoid, serratus anterior, upper, middle and lower fibers of trapezius was recorded during shoulder abduction movements executed holding the scapula in neutral, retracted and protracted position, and subsequently a shoulder elevation movement. The activation of each muscle and the scapulothoracic muscles activity ratios were determined every 15 degrees, from 15° to 120° of abduction.

Scapular retraction led to higher activation of the entire trapezius muscle, whereas protraction induced higher upper trapezius, middle deltoid and serratus anterior activity, along with lower activity of middle and lower trapezius. Shoulder elevation led to higher activity of the upper trapezius and middle deltoid. Moreover, it induced lower activation of the serratus anterior and middle and lower trapezius, thus leading to high ratios between the upper trapezius and the other scapulothoracic muscles, especially between 15 and 75 degrees of abduction.

This study highlights that shoulder abduction performed with scapular protraction and in combination with scapular elevation leads to increased activity of the middle deltoid and upper trapezius, resulting in imbalances between the scapulothoracic muscles that could hamper the optimal scapulohumeral rhythm. The abduction performed in the aforementioned scapular conditions also induce potential reciprocal inhibition effects between the movers and stabilizers muscles of scapula, suggesting different motor control strategies of integrating a common shoulder movement with various modification of the scapular position.

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1. Introduction

Optimal shoulder girdle function depends on smooth and coordinated movement of glenohumeral (GH) and scapulothoracic (ST) joints, commonly known as *scapulohumeral rhythm* (Neumann, 2010). During upper limb elevation movements, this rhythm is regulated by the activity of GH muscles (deltoid muscle and rotator cuff muscles) and specific ST muscles (upper, middle and lower fibers of trapezius muscle, and serratus anterior) (Neumann, 2010). More specifically, the temporal sequence of recruitment, the level of activation, and the balance between these muscles are fundamental factors in coordinating scapular and humeral movements (Contemori & Biscarini, 2017; Cools et al., 2003, 2007; Neumann, 2010).

Taken individually, each ST muscle generates different scapular-on-thorax sliding movements. Specifically, the upper trapezius (UT) and the lower trapezius (LT) act as scapular elevator and depressor, while the middle trapezius (MT) and the serratus anterior (SA) act as scapular retractor and protractor (Neumann, 2010). Nevertheless, during shoulder elevation movements such as shoulder abduction, the ST muscles are activated synergistically serving a critical role for the glenohumeral arthrokinematics. Indeed, during the shoulder abduction, the UT and the SA generate the propulsive force necessary to upwardly rotate the scapula, while the MT and LT act as scapula-on-thorax stabilizers (Ekstrom, Donatelli, & Soderberg, 2003; Johnson & Pandyan, 2005; Neumann, 2010). The stability provided by the LT and MT is fundamental to counteract the scapular elevation and protraction induced by the activity of the UT and SA, and ultimately provides a stable axis of rotation for the scapula. The upward rotation of the scapula serves three fundamental shoulder girdle functions (Neumann, 2010): faces the glenoid fossa upward, providing a structural base to maximize the upward and lateral reach of the upper limb; preserves the optimal length-tension relationship of the abductor muscles of the GH joint; limits the reduction of the subacromial space induced by the action of the middle deltoid (MD).

Commonly, GH abduction is performed moving the humerus in the scapular plane with the scapula in a *neutral* position. However, the same movement can be done in different scapular positions. For instance, GH abduction can be performed holding the scapula in a *retracted* position as well as in a *protracted* position (Guney-Deniz, Harput, Toprak, & Duzgun, 2018; Harput et al., 2018; Lee, Moon, & Lee, 2016; Malmström, Olsson, Baldetorp, & Fransson, 2015). Moreover, the elevation of the humerus can be preceded by a scapular elevation induced by the activation of the UT. The shoulder elevation had also been identified during arm elevation among people with poor shoulder posture (Thigpen, Padua, & Michener, 2010). Therefore, the abduction of the shoulder can be executed in different combinations of scapular position and scapular elevation.

A review of the existing literature highlights that the activity of GH and ST muscles has been broadly evaluated in presence of several shoulder girdle pathologies, including impingement syndrome, scapular dyskinesis and infraspinatus muscle atrophy (Contemori & Biscarini, 2017; Contemori et al., 2018; Cools, Declercq, Cambier, Mahieu, & Witvrouw, 2007; Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003; Lopes, Timmons, & Grover, 2014; Page, 2011). Of interest, preceding research studies have also assessed the balance between ST muscles in terms of UT/LT, UT/MT, and UT/SA activity ratios (Contemori & Biscarini, 2017; Cools et al., 2007). However, information about the pattern of activation of the shoulder girdle muscles in healthy conditions is more limited. In particular, to our knowledge, only few studies had been conducted in healthy subjects to assess the activation strategies of the shoulder girdle muscles during GH movements in different scapular positions (Guney-Deniz et al., 2018; Harput et al., 2018; Lee et al., 2016; Malmström et al., 2015; Picco, Fischer, & Dickerson, 2010). Moreover, no study had analyzed the same movements together with voluntary scapular elevation.

We hypothesized that shoulder abduction performed in neutral, retracted, and protracted scapular position would lead to totally different patterns of activation of the deltoid muscle, and would change the activation relationships between the ST muscles. In addition, we hypothesized that shoulder abduction executed in different scapular positions and in combination with scapular elevation would lead to increased activation of the UT, concurrently with different activation patterns of the other shoulder girdle muscles and different ST muscles relationships, as compared to the same movements performed without scapular activation. This information would enhance the existing knowledge about shoulder muscles activation patterns and the relationships between the ST muscles, along with new insights about the motor control strategies of the shoulder. For this purpose, the muscle activity amplitude and the ST muscles activity ratios of healthy people's shoulder muscles (MD, UT, MT, LT, and SA) was evaluated during GH abduction performed in different combinations of scapular positioning (neutral scapular position, retracted scapular position, and protracted scapular position), with and without scapular elevation.

2. Materials and methods

2.1. Participants

12 female and 18 male participants (mean age 23.7 years, range 18–32 years; mean height 1.77 m, range 1.69–1.87 m; mean body mass 70.87 kg, range 64–81 kg) free from shoulder pain, totally able to perform overhead activities without pain or discomfort, without history of shoulder injuries, and with normal shoulder posture, were recruited from local fitness centers. Normal shoulder posture was defined as absence of forward head posture, evident thoracic kyphosis, and anterior shoulder position (Thigpen et al., 2010). All participants were free of cognitive deficits and were not using any psychoactive drug or medication at the time of the test.

All participants gave informed consent to their inclusion in the study, which was conducted in accordance with the Declaration of Helsinki, and was approved by the local university ethics committee.

Fig. 1. Starting positions adopted to assess the activity of the shoulder girdle muscle during shoulder abduction performed in neutral scapular position (A), retracted scapular position (B), protracted scapular position (C), neutral scapular position with scapular elevation (D), retracted scapular position with scapular elevation (E) and protracted scapular position with scapular elevation (F).

2.2. Testing session

At the beginning of the testing session, each participant performed a maximal voluntary isometric contraction (MVIC) in manual resistance tests specific to each muscle of interest, for offline EMG signal normalization. The MVIC test was conducted following a procedure detailed in a previous work from our laboratory (Contemori & Biscarini, 2017). Each position was held for 5 s and a rest period of 2 min was given between testing on different muscles. The whole MVIC test procedure was repeated two times.

After the MVIC test and a full recovery, the activity of the selected muscles was recorded during *full can* GH abduction executed in different combinations of scapular positioning (neutral, retracted, and protracted) and scapular elevation. Participants were instructed to not perform scapular retraction and protraction until the end range, but to retract and protract the scapula until the shoulder abduction could be performed easily and without discomfort. For the scope of the test, it was fundamental that participants moved their humerus in line with the scapular plane in each scapular position. Therefore, in addition to verbal and visual demonstrations, the upper limb of each subject was passively moved by the examiner, in the ideal trajectory 5–6 times, in order to reinforce the perception of the kinematic patterns. Participants were also encouraged to perform a minimum of three practice trials for each task until they were comfortable with the movements. Once this familiarization phase was completed, participants performed 8 repetitions of each movement. Initially participants had to abduct their dominant humerus with the scapula in neutral position, then they repeated the same task while holding the scapula in retracted position, and finally in protracted scapular position. After this primary series of movements, participants had to repeat the same tasks executing a scapular elevation movement immediately before the GH abduction. An overview of the different exercises is outlined in Fig. 1. Each movement started with the upper limb relaxed

along the side and, from this position, participants moved their shoulder just above 120° of abduction. To standardize the cadence of movement (1-second concentric phase and a 1-second eccentric phase), audible acoustic signals were provided with a metronome set at 2 beats per second (0.5 Hz frequency). Two minutes of rest were given between the trials to avoid fatigue.

2.3. EMG data recording and processing

Wireless EMG sensors (FREEEMG 1000, BTS Bioengineering, Milano, Italy) were used to record sEMG signals from MD, UT, MT, LT, and SA muscles of participants' dominant shoulder. Participants were asked to hold a normal posture with the upper limbs relaxed along the thorax while the examiner placed the EMG electrodes on the skin. The EMG electrodes were placed on the centre of the muscle belly, with a centre-to-centre electrodes distance of about 1.5 cm, in the direction of the muscle fibers, according to the "European recommendations for surface electromyography" (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000).

Raw EMG signals were differentially amplified (933 gain), band-pass filtered (10–500 Hz), and digitalized (16-bit resolution, 1-kHz sampling frequency) within the wireless EMG sensors. Electromyographic signals were then transformed into amplitude envelopes through a point-to-point moving root mean square filter (500-millisecond time interval), normalized to the peak EMG amplitude at MVIC, and expressed as a percentage of its value (Biscarini, Contemori, Busti, Botti, & Pettorossi, 2016; Contemori & Biscarini, 2017). The muscle level of activation during the movement was determined excluding the first and the last repetitions, and computing the mean muscle activation recorded during the 6 intermediate repetitions. The muscle activity level was then determined every 15 degrees within the range of motion of shoulder abduction (15, 30, 45, …, 120°). The same procedure was followed for each abduction task and for each muscle analyzed. The "Smart Analyzer®" software (BTS Bioengineering, Milano, Italy) was used for the whole process of signal processing.

2.4. Kinematic data recording and analysis

The upper limb 3D kinematics were recorded with the use of a eight-camera "Smart-DX 6000" optoelectronic motion capture system and analyzed with the "Smart Analyzer®" software (BTS Bioengineering, Milano, Italy).

Following the guidelines defined by the "shoulder sub-committee" of the "International Society of Biomechanics committee for standardization and terminology" (Wu et al., 2005), a set of 13 skin-mounted reflective markers, spherical in shape and 5 mm in diameter, were attached to the following anatomical landmarks: the spinous processes of the seventh cervical vertebra and the eighth thoracic vertebra, the sternal notch, the xiphoid process, the lateral aspect of the acromion of both scapula, the medial and lateral epicondyle of dominant upper limb's elbow, the radial and ulnar styloid of dominant upper limb's wrist, the anterior superior iliac spine of both iliac bones, and the second spinous processes of the sacrum. This set of markers enabled a detailed analysis of the upper limb kinematics and a precise determination of the shoulder range of motion (Contemori & Biscarini, 2017; Contemori & Biscarini, 2018; Ippolito et al., 2016; Wu et al., 2005). In addition, the displacement of the marker mounted on the acromion of the dominant upper limb was recorded to assess the level of retraction and protraction of the scapula. The neutral scapular position was considered as the *zero* reference, and the level of scapular retraction/protraction was computed as posterior/anterior displacement of the acromion marker relative to neutral scapular position (Fig. 2). The marker position was recorded immediately before the start of the movement. For each movement analyzed, the position of the acromion mounted marker was averaged across the 6 intermediate repetitions of the 8 completed repetitions.

2.5. Statistical analysis

Two analysis of variance (ANOVA) models were applied for data analysis, as the normality of the distribution in the dependent variable was previously confirmed through the Shapiro-Wilk test with statistical significance designated at 0.05.

The amplitude of the EMG from muscle was analyzed with a 3-way ANOVA design, with scapular position (neutral, retracted, protracted), scapular elevation (without scapular elevation, with scapular elevation) and shoulder abduction angle (15°, 30°, 45°, 60°, 75°, 90°, 105°, 120°) as independent within-subject factors. The same ANOVA design (scapular position × scapular elevation × angle) was applied for the analysis of the scapulothoracic muscles activity ratios (UT/MT, UT/LT, and UT/SA).

Post hoc analysis was performed with the Scheffé test and statistical significance was designated at $P < 0.05$. Partial eta squared (η_p^2) was also computed to estimate the effect size of significant main effects and interactions. In addition, the "observed power" ω (ranging from 0 to 1) was calculated to assess the statistical power of the results.

A one-sample *t*-test was adopted to assess the statistical significance of the posterior/anterior displacement of the acromion marker in retracted/protracted scapular position, relative to neutral scapular position. A paired *t*-test was used to compare the displacement of the acromion marker in retracted and protracted scapular position. The statistical significance for the paired *t*-test was designated at $P < 0.05$.

3. Results

3.1. Acromion marker displacement

The one-sample *t*-test revealed significant posterior displacement of the acromion marker in scapular retraction

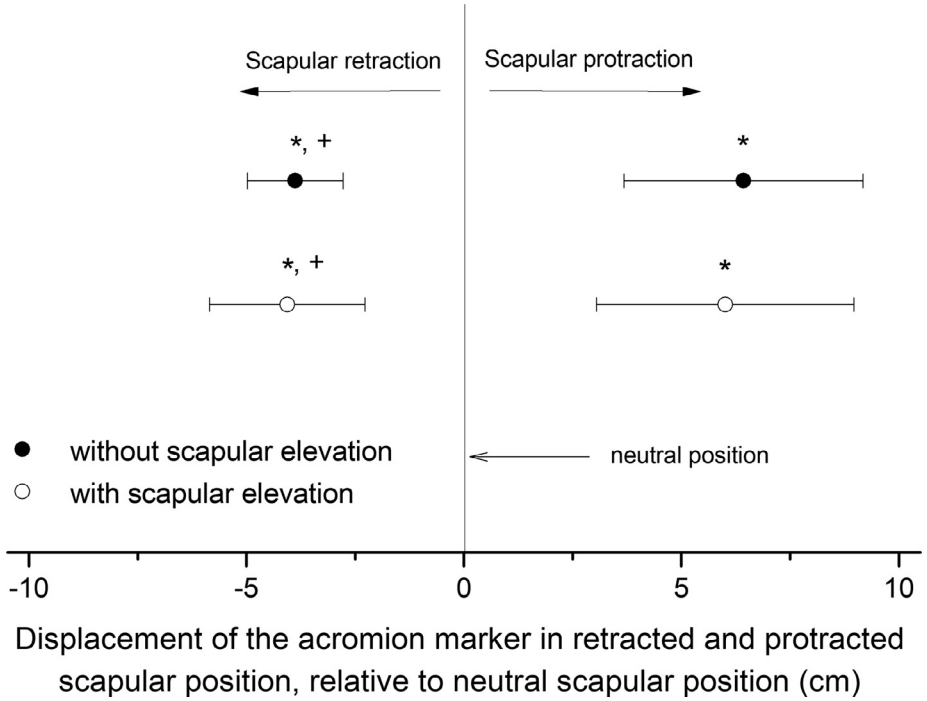

Fig. 2. Anterior displacement (positive values) of the acromion marker in the protracted scapular position, relative to neutral scapular position, and posterior displacement (negative values) of the acromion marker in the retracted scapular position, relative to neutral scapular position. Significant difference between scapular positions: neutral-retracted difference, * P < 0.001; neutral-protracted difference, * P < 0.001; retracted-protracted difference, + P < 0.001.

($P < 0.001$, $\omega = 1.0$), and significant anterior displacement of the acromion marker in scapular protraction ($P < 0.001$, $\omega = 1.0$), relative to neutral scapular position (Fig. 2).

The paired *t*-test revealed a statistical significant difference between the displacement of the acromion marker in scapular retraction and protraction ($P < 0.001$, $\omega = 1.0$). These results were found either for shoulder abduction movements without scapular elevation and with scapular elevation.

3.2. Middle deltoid

The analysis of MD activity revealed significant *position* main effect ($P < 0.001$, $\eta_p^2 = 0.475$, $\omega = 0.99$), *elevation* main effect ($P = 0.001$, $\eta_p^2 = 0.301$, $\omega = 0.93$), *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.301$, $\omega = 1$), interaction between *position* and *elevation* ($P < 0.001$, $\eta_p^2 = 0.442$, $\omega = 0.98$), interaction between *position* and *angle* ($P < 0.001$, $\eta_p^2 = 0.841$, $\omega = 0.99$), and interaction between *elevation* and *angle* ($P = 0.023$, $\eta_p^2 = 0.474$, $\omega = 0.83$). Without scapular elevation, the MD activity was significantly higher in protracted scapular position than in neutral and retracted positions (Fig. 3). The MD activity in neutral and retracted positions was significantly higher with scapular elevation than without (Fig. 3).

3.3. Upper trapezius

The analysis of UT activity revealed significant *position* main effect ($P < 0.001$, $\eta_p^2 = 0.669$, $\omega = 1.0$), *elevation* main effect ($P < 0.001$, $\eta_p^2 = 0.726$, $\omega = 1.0$), *angle* main effect ($P = 0.03$, $\eta_p^2 = 0.458$, $\omega = 0.81$), interaction between *position* and *elevation* ($P < 0.001$, $\eta_p^2 = 0.474$, $\omega = 0.99$), interaction between *position* and *angle* ($P < 0.001$, $\eta_p^2 = 0.847$, $\omega = 0.99$), and interaction between *elevation* and *angle* ($P < 0.001$, $\eta_p^2 = 0.832$, $\omega = 1$). Without scapular elevation, the UT activity was significantly higher in protracted and retracted scapular position than in neutral scapular position (Fig. 4). In all the scapular positions, the UT activity was significantly higher with scapular elevation than without (Fig. 4).

3.4. Middle trapezius

The analysis of MT activity revealed significant *position* main effect ($P < 0.001$, $\eta_p^2 = 0.845$, $\omega = 1.0$), *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.877$, $\omega = 1$), interaction between *position* and *elevation* ($P = 0.016$, $\eta_p^2 = 0.257$, $\omega = 0.76$), interaction between *position* and *angle* ($P < 0.001$, $\eta_p^2 = 0.898$, $\omega = 1$), and interaction between *elevation* and *angle* ($P = 0.002$, $\eta_p^2 = 0.584$, $\omega = 0.97$). The

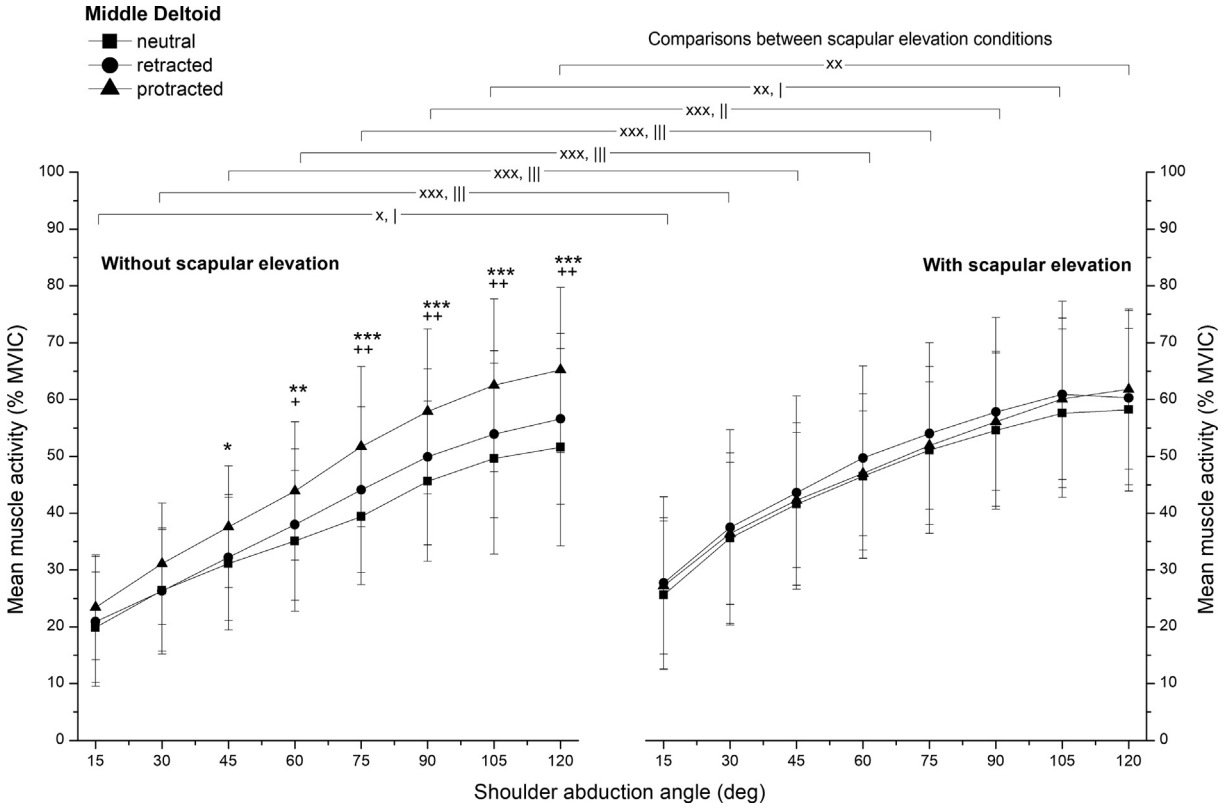

Fig. 3. Dependence on the shoulder abduction angle of the middle deltoid mean EMG activity, expressed as a percentage of the peak electromyographic amplitude at MVIC. Significant difference between scapular positions: neutral-protracted difference, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; retracted-protracted difference, + $P < 0.05$, ++ $P < 0.01$, +++ $P < 0.001$. Significant difference between scapular elevation conditions: for neutral scapular position, x $P < 0.05$, xx $P < 0.01$, xxx $P < 0.001$; for retracted scapular position, | $P < 0.05$, || $P < 0.01$, ||| $P < 0.001$.

MT activity was significantly higher in retracted and neutral scapular position than in protracted position, and significantly higher in retracted than in neutral position, both with and without scapular elevation (Fig. 5). The MT activity was significantly lower with scapular elevation than without, but only for retracted scapular position (Fig. 5).

3.5. Lower trapezius

The analysis of LT activity revealed significant *position* main effect ($P < 0.001$, $\eta_p^2 = 0.726$, $\omega = 1.0$), *elevation* main effect ($P = 0.017$, $\eta_p^2 = 0.182$, $\omega = 0.69$), and *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.872$, $\omega = 1$). The LT activity was significantly higher in retracted scapular position than in neutral and protracted positions, both with and without scapular elevation (Fig. 6). The LT activity was significantly lower with scapular elevation than without, but only for retracted scapular position (Fig. 6).

3.6. Serratus anterior

The analysis of SA activity revealed significant *position* main effect ($P = 0.009$, $\eta_p^2 = 0.285$, $\omega = 0.85$), *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.909$, $\omega = 1$), interaction between *position* and *elevation* ($P = 0.025$, $\eta_p^2 = 0.232$, $\omega = 0.69$), interaction between *position* and *angle* ($P = 0.002$, $\eta_p^2 = 0.807$, $\omega = 0.99$), and interaction between *elevation* and *angle* ($P = 0.001$, $\eta_p^2 = 0.632$, $\omega = 0.99$). Without scapular elevation, the SA activity was significantly higher in protracted scapular position than in neutral and retracted scapular position, but only from 75° to 120° of abduction (Fig. 7). The SA activity in protracted scapular position was significantly lower with scapular elevation than without, but only from 90° to 120° (Fig. 7).

3.7. UT/MT ratio

The analysis of UT/MT ratio revealed significant *position* main effect ($P < 0.001$, $\eta_p^2 = 0.707$, $\omega = 1.0$), *elevation* main effect ($P < 0.001$, $\eta_p^2 = 0.554$, $\omega = 1.0$), *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.674$, $\omega = 0.99$), interaction between *position* and *angle* ($P = 0.046$, $\eta_p^2 = 0.68$, $\omega = 0.81$), and interaction between *elevation* and *angle* ($P = 0.001$, $\eta_p^2 = 0.621$, $\omega = 0.99$). The UT/MT ratio

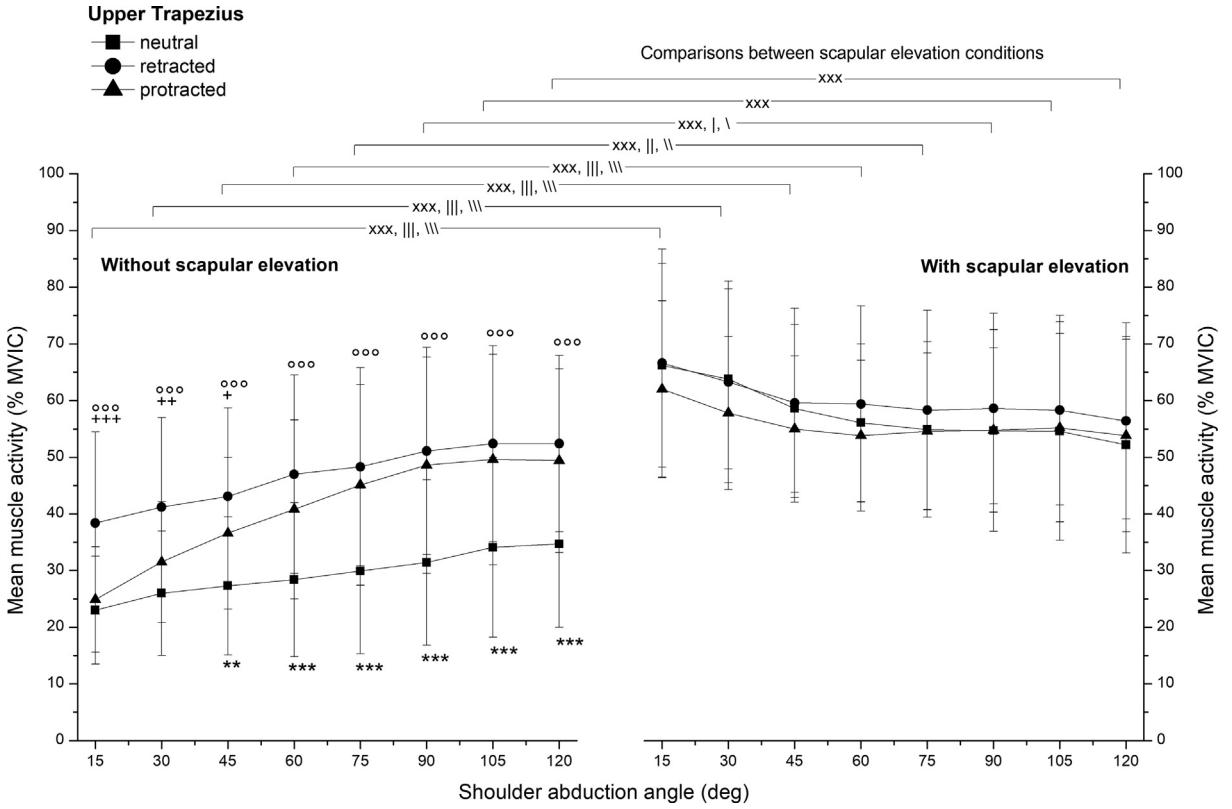

Fig. 4. Dependence on the shoulder abduction angle of the upper trapezius mean EMG activity, expressed as a percentage of the peak electromyographic amplitude at MVIC. Significant difference between scapular positions: neutral-retracted difference, °°° $P < 0.001$; neutral-protracted difference, ** $P < 0.01$, *** $P < 0.001$; retracted-protracted difference, + $P < 0.05$, + + $P < 0.01$, + + + $P < 0.001$. Significant difference between scapular elevation conditions: for neutral scapular position, xxx $P < 0.001$; for retracted scapular position, | $P < 0.05$, || $P < 0.01$, ||| $P < 0.001$; for protracted scapular position, \ $P < 0.05$, \\ $P < 0.01$, \\\ $P < 0.001$.

was significantly higher in protracted scapular position than in neutral and retracted scapular position, both with and without scapular elevation (Table 1). In all scapular positions, the UT/MT ratio was significantly higher with scapular elevation than without (Table 1).

3.8. UT/LT ratio

The analysis of UT/LT ratio revealed a significant *position* main effect ($P < 0.001$, $\eta_p^2 = 0.447$, $\omega = 0.99$), significant *elevation* main effect ($P < 0.001$, $\eta_p^2 = 0.604$, $\omega = 1.0$), *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.819$, $\omega = 1$), interaction between *position* and *angle* ($P = 0.002$, $\eta_p^2 = 0.807$, $\omega = 0.99$), and interaction between *elevation* and *angle* ($P < 0.001$, $\eta_p^2 = 0.653$, $\omega = 0.99$). Without scapular elevation, the UT/LT ratio was significantly higher in protracted than in retracted scapular position, but only from 15° to 60° of abduction (Table 2). In all scapular positions, the UT/LT ratio was significantly higher with scapular elevation than without, especially from 15° to 75° (Table 2).

3.9. UT/SA ratio

The analysis of UT/SA ratio revealed significant *position* main effect ($P = 0.007$, $\eta_p^2 = 0.296$, $\omega = 0.84$), *elevation* main effect ($P < 0.001$, $\eta_p^2 = 0.424$, $\omega = 0.99$), *angle* main effect ($P < 0.001$, $\eta_p^2 = 0.777$, $\omega = 1$), interaction between *position* and *elevation* ($P = 0.003$, $\eta_p^2 = 0.334$, $\omega = 0.89$), and interaction between *elevation* and *angle* ($P = 0.007$, $\eta_p^2 = 0.534$, $\omega = 0.92$). Without scapular elevation, the UT/SA ratio was significantly higher in retracted scapular position than in neutral and protracted scapular position, but only from 15° to 60° for neutral scapular position, and from 15° to 45° for protracted scapular position (Table 3). No difference was found between the scapular positions with scapular elevation. The UT/SA ratio was significantly higher with scapular elevation than without, but only in neutral and protracted scapular position (Table 3).

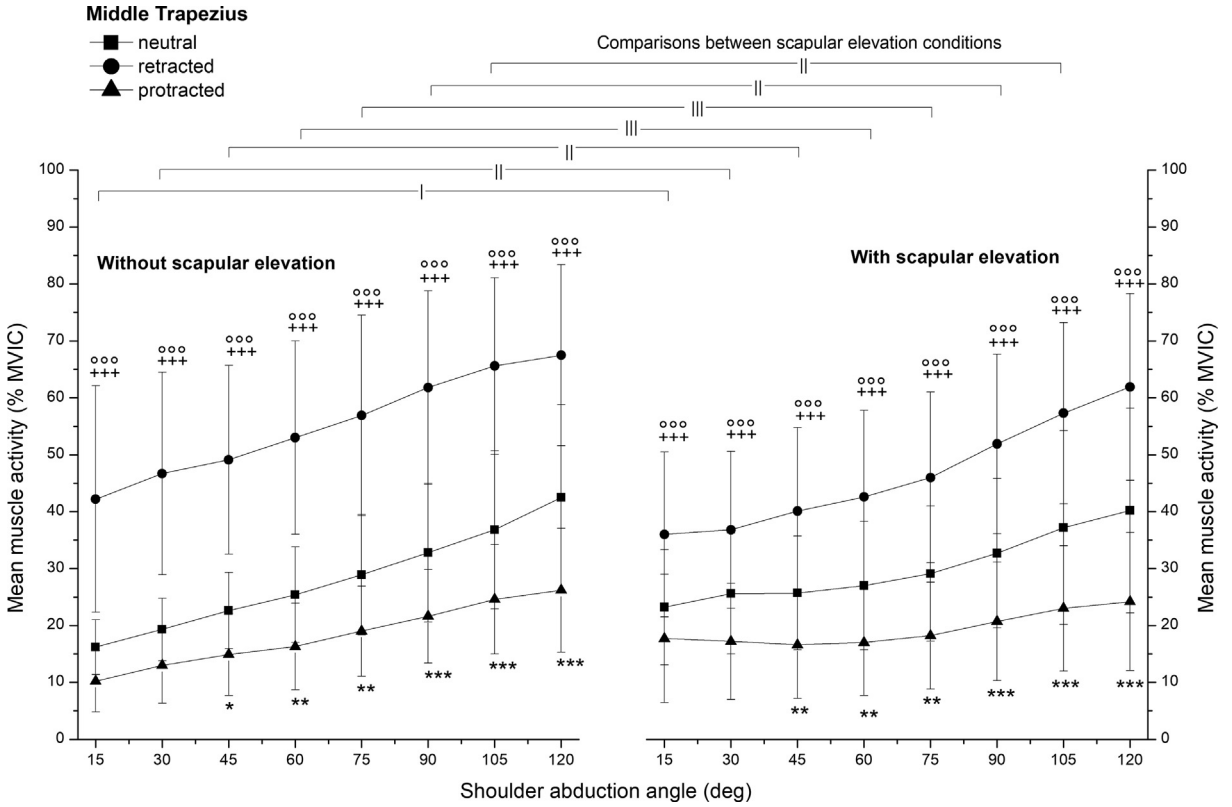

Fig. 5. Dependence on the shoulder abduction angle of the middle trapezius mean EMG activity, expressed as a percentage of the peak electromyographic amplitude at MVIC. Significant difference between scapular positions: neutral-retracted difference, °°° $P < 0.001$; neutral-protracted difference, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; retracted-protracted difference, + + + $P < 0.001$. Significant difference between scapular elevation conditions: for retracted scapular position, | $P < 0.05$, || $P < 0.01$, ||| $P < 0.001$.

4. Discussion

This study has analyzed the effects of different combinations of scapular position and scapular elevation on the electromyographic activity of relevant shoulder girdle muscles and on ST muscles activity ratios, during glenohumeral abduction movements. The results highlight that scapular protraction and scapular elevation lead to increased activity of the MD and UT, along with reduced activity of the MT and LT during shoulder abduction. These patterns of activation result in higher ratios between the UT and the other muscles that act on the scapula, with potential implications on the optimal function of the ST joint and, as consequence, on the GH joint.

The activity of the MD was significantly enhanced by the scapular protraction and scapular elevation (Fig. 3). Since the MD acts only on the GH joint, the changes in its activity in response to different ST joint arrangements represent an interesting finding. In particular, the MD was more active in those conditions that facilitate the UT activation (Fig. 4), suggesting an important role of the UT on glenohumeral mechanics and, as a consequence, on MD activity. Protracted shoulder position and scapular elevation could potentially lead to inefficient coordination between the scapula and the humerus, resulting in greater deltoid force needed to abduct the shoulder. Of interest, when the upper limb is at rest along the thorax, the scapular elevation is followed thorough a slight downward rotation of the scapula (Neumann, 2010). The downwardly rotated scapula orients the glenoid fossa vertically reducing the compressive force that stabilizes the head of the humerus on the glenoid, and exposing the humerus to a downward traction force induced by the force of gravity (Neumann, 2010). This condition accounts for the increased deltoid activity with scapular elevation, since the MD is the only muscle with a line of force that can counteract the force of gravity. Nevertheless, higher deltoid activity could hamper the optimal arthrokinematic of the GH joint. In fact, increased deltoid activity has been reported to result in increased superior translation of the humeral head (Parsons, Apreleva, Fu, & Woo, 2002; San Juan, Kosek, & Karduna, 2013). Therefore, humeral elevation movements that induce higher deltoid activity (Fig. 3) could actually increase the risk of subacromial impingement due to the superior translation of the humeral head induced by the deltoid action.

The retraction of the scapula leads to increased activation of all trapezius portions (Figs. 4–6). Although this was expected for the MT considering its primary role as scapular retractor (Guney-Deniz et al., 2018; Neumann, 2010), the increased activity of the UT and LT in retracted scapular position is an interesting finding. Specifically, these results demonstrate that the upper and lower fibers of the trapezius muscle do not only act as scapular elevator and depressor, respectively, but also as scapular retractors in synergy with the MT. The increased activity of the LT during abduction with the scapula in retracted position could be further explained by scapular

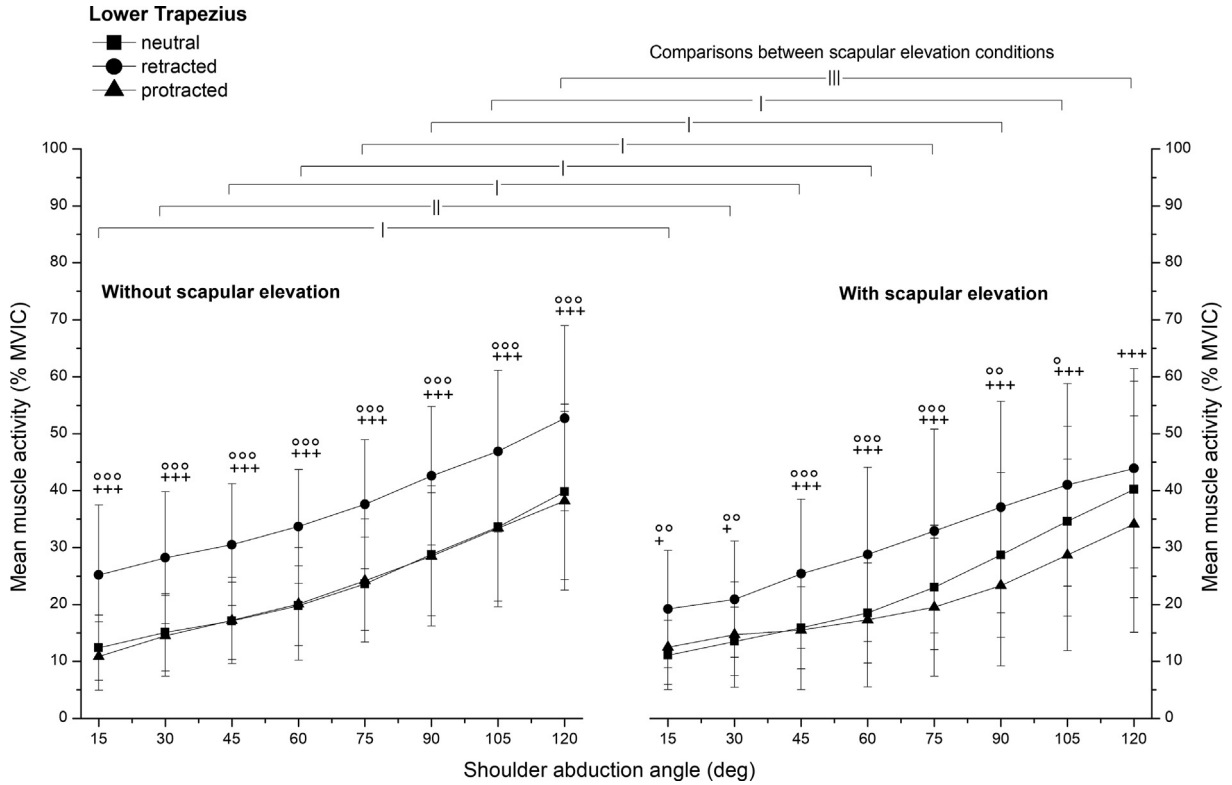

Fig. 6. Dependence on the shoulder abduction angle of the lower trapezius mean EMG activity, expressed as a percentage of the peak electromyographic amplitude at MVIC. Significant difference between scapular positions: neutral-retracted difference, ° $P < 0.05$, °° $P < 0.01$, °°° $P < 0.001$; retracted-protracted difference, + $P < 0.05$, +++ $P < 0.001$. Significant difference between scapular elevation conditions: for retracted scapular position, | $P < 0.05$, || $P < 0.01$, ||| $P < 0.001$.

kinematics. Indeed, scapular retraction occurs through a summation of scapular adduction, external rotation, and posterior tilt (Neumann, 2010). Of interest, scapular adduction and external rotation are performed by MT and rhomboid major muscles, whereas the posterior tilt of the scapula is mainly due to the action of the LT (Neumann, 2010), which accounts for the increased activation of the lower fibers of the trapezius muscle recorded in retracted scapular position (Fig. 6).

Similarly to the results of a preceding study on slouched body posture (Malmström et al., 2015), the UT activity is enhanced during shoulder abduction in protracted scapular position, without scapular elevation (Fig. 4). This could be due to an increased resistance opposed to scapular upward rotation by the protraction of the scapula. Indeed, the scapular protraction is provoked by the action of the SA (Fig. 7) and pectoralis minor. The pectoralis minor determines some scapular movements that are exactly the opposite of those provoked by UT. Specifically, the pectoralis minor is a downward rotator, a depressor, an anterior tilter, an internal rotator, and an abductor of the scapula (Neumann, 2010). Noteworthy, scapular protraction occurs through a summation of scapular abduction, internal rotation, and anterior tilt, which are all secondary to the action of pectoralis minor (Neumann, 2010). Moreover, previous research studies on scapular kinematics highlighted that protracted scapular position, secondary to slouched body posture and rounded shoulder posture, led to a significant increase of scapular anterior tilt and internal rotation (Finley & Lee, 2003; Thigpen et al., 2010). Given that, we may assume that protracted scapular position is associated with a shortening in pectoralis minor length. Of interest, decreased resting length of the pectoralis minor has also been reported to negatively affect the scapular kinematics (Borstad & Ludewig, 2005). Thus, with a protracted scapular position and a consequent shortened pectoralis minor the UT likely has to increase its activity to upwardly rotate the scapula.

Differently from the UT, the shoulder abduction performed in protracted scapular position is characterized by a low level of MT activity (Fig. 5), that also results in high UT/MT activity ratio (Table 1). During shoulder abduction in neutral scapular position the MT mainly act to stabilize the scapula in the transversal plane, in order to counteract the scapular protraction induced by the SA. The low MT activity recorded during shoulder abduction in scapular protraction could suggest a lower need for scapular transverse stability, in addition to a muscular activation strategy useful to not limit the action of the SA that is more active in protracted scapular position (Fig. 7). Such finding could suggest the existence of a reciprocal inhibition between SA and MT when the scapula is protracted. However, a potential effect of MT elongation on its activity should not be excluded. Indeed, scapular protraction stretches the MT fibres and thus changes the point of the length-tension curve at which the MT starts its contraction. Therefore, it is possible that in elongated condition, the MT requires a lower level of activation to provide scapular transverse stability. Of interest, our results regarding the MT activity in protracted shoulder position are in contrast with those of a preceding work, that highlighted increased

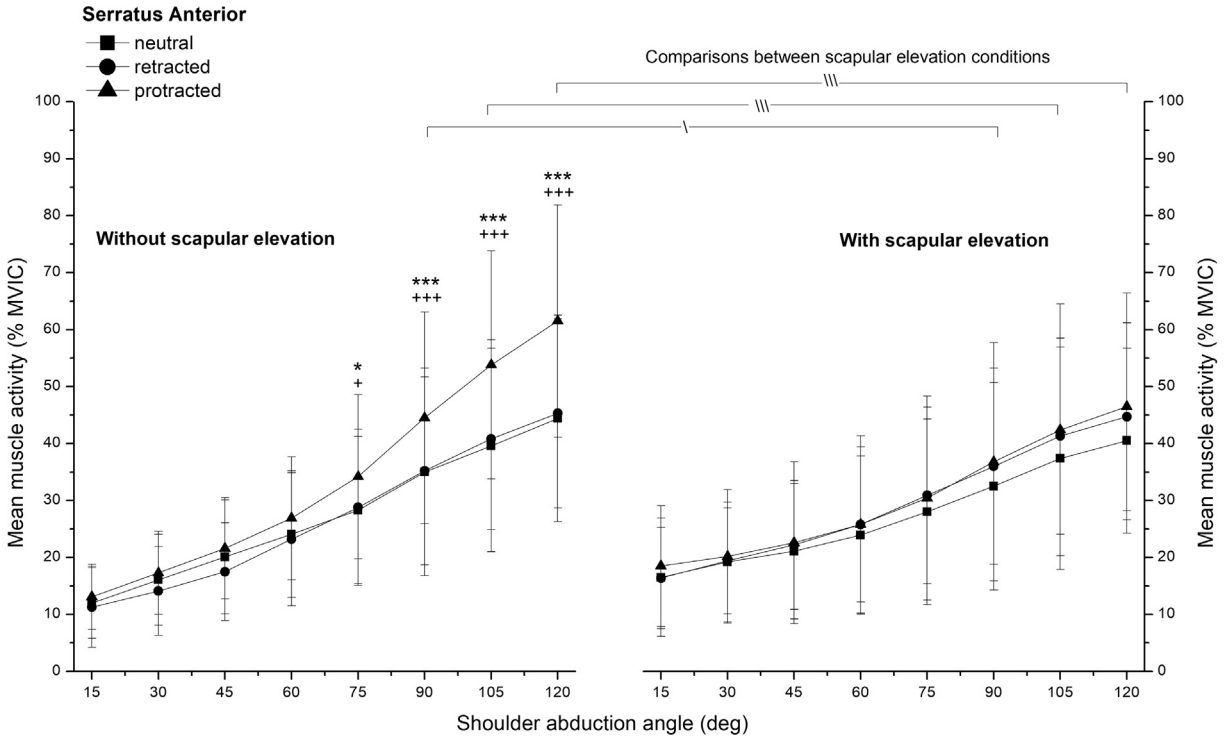

Fig. 7. Dependence on the shoulder abduction angle of the serratus anterior mean EMG activity, expressed as a percentage of the peak electromyographic amplitude at MVIC. Significant difference between scapular positions: neutral-protracted difference, * $P < 0.05$, *** $P < 0.001$; retracted-protracted difference, + $P < 0.05$, +++ $P < 0.001$. Significant difference between scapular elevation conditions: for protracted scapular position, \\ $P < 0.01$, \\\ $P < 0.001$.

Table 1
UT/MT activity ratio recorded during shoulder abduction movement with the scapula in neutral, retracted and protracted position, and with or without scapular elevation. Data reported as mean (standard deviation).

Shoulder abduction angle	Without scapular elevation			With scapular elevation		
	NSP	RSP	PSP	NSP	RSP	PSP
15	1.59 (1.13)$^{***, xxx}$	1.06 (0.56)$^{+++, xxx}$	3.37 (2.85)^{xxx}	3.44 (1.92)***	2.32 (1.85)$^{+++}$	4.90 (3.19)
30	1.51 (1.11)$^{***, xxx}$	1.04 (0.65)$^{+++, xxx}$	3.14 (2.14)^{xxx}	2.88 (1.36)***	2.16 (1.85)$^{+++}$	4.53 (2.78)
45	1.33 (0.95)$^{***, xxx}$	1.03 (0.65)$^{+++, xxx}$	3.00 (1.84)^{xx}	2.63 (1.25)***	1.82 (1.27)$^{+++}$	4.25 (2.34)
60	1.23 (0.87)$^{***, xxx}$	1.03 (0.65)$^{+++, xx}$	2.97 (1.65)^{x}	2.46 (1.37)***	1.59 (0.82)$^{+++}$	3.93 (1.99)
75	1.15 (0.75)$^{***, xxx}$	0.96 (0.55)$^{+++, x}$	2.71 (1.31)^{x}	1.25 (1.34)***	1.43 (0.69)$^{+++}$	3.61 (1.65)
90	1.04 (0.60)$^{***, xxx}$	0.90 (0.43)$^{+++, x}$	2.49 (1.08)	1.95 (1.15)**	1.27 (0.60)$^{+++}$	3.16 (1.43)
105	0.99 (0.49)$^{***, xxx}$	0.85 (0.35)$^{+++}$	2.32 (1.18)	1.74 (1.09)**	1.11 (0.47)$^{+++}$	2.84 (1.32)
120	0.87 (0.39)$^{***, xxx}$	0.81 (0.30)$^{+++}$	2.25 (1.23)	1.52 (1.00)**	0.98 (0.42)$^{+++}$	2.69 (1.31)

NSP, neutral scapular position; RSP, retracted scapular position; PSP, protracted scapular position.
Significant differences between scapular positions: NSP-PSP difference, ** $P < 0.01$, *** $P < 0.001$; RSP-PSP difference, +++ $P < 0.001$.
Significant differences between scapular elevation conditions: x $P < 0.05$, xx $P < 0.01$, xxx $P < 0.001$.

MT activation during shoulder abduction in slouched sitting posture (Lee et al., 2016). These different results could suggest a various motor control strategy of the shoulder muscles between isolated scapular protraction and total body slouched posture. Indeed, scapular protraction secondary to slouched body posture is induced yielding passively to the force of gravity. On the contrary, the active scapular protraction movement adopted in the present study required the voluntary activation of scapular protractors muscles, such as the SA (Fig. 7). This aspect further supports the hypothesis of a reciprocal inhibition between scapular protractors and retractors, which accounts for the increased SA activity and reduced activity of MT recorded during abduction with active protraction of the scapula (Figs. 5 and 7).

The increased UT activity secondary to shoulder elevation (Fig. 4) was followed through a reduced activation of MT and LT in retracted scapular position (Figs. 5 and 6), thus leading to high UT/MT and UT/LT ratios (Table 1 and 2). This could suggest the existence of a fine activity coordination between the trapezius muscle portions, in order to not counteract the action of the UT and promote smooth scapular movements. Of interest, high UT/MT and UT/LT ratios have previously been found in pathologic shoulder

Table 2
UT/LT activity ratio recorded during shoulder abduction movement with the scapula in neutral, retracted and protracted position, and with or without scapular elevation. Data reported as mean (standard deviation).

Shoulder abduction angle	Without scapular elevation			With scapular elevation		
	NSP	RSP	PSP	NSP	RSP	PSP
15	2.35 (1.80)^{xxx}	1.90 (1.23)$^{++,\ xxx}$	3.23 (2.74)^{xxx}	8.55 (6.96)	4.49 (2.70)	6.60 (4.47)
30	2.67 (4.46)^{xxx}	1.76 (1.08)$^{+,\ xxx}$	2.77 (1.80)^{xxx}	6.14 (4.19)	3.95 (2.70)	5.98 (5.00)
45	2.32 (3.65)^{xx}	1.65 (0.96)$^{+,\ xxx}$	2.70 (2.01)^{xxx}	4.98 (3.68)	3.21 (2.54)	5.50 (5.34)
60	1.96 (2.81)^{xx}	1.58 (0.90)$^{+,\ xxx}$	2.58 (1.66)^{xx}	4.25 (3.54)	2.87 (2.38)	4.78 (4.71)
75	1.61 (1.77)^{x}	1.46 (0.84)^{xx}	2.19 (1.11)^{xx}	3.49 (3.61)	2.48 (1.98)	4.15 (4.17)
90	1.37 (1.36)	1.32 (0.70)^{xx}	1.96 (0.92)^{x}	3.09 (4.56)	2.20 (1.94)	3.43 (3.41)
105	1.25 (1.25)	1.23 (0.61)^{x}	1.71 (0.84)	2.81 (5.05)	1.96 (1.90)	2.85 (3.02)
120	1.07 (1.04)	1.10 (0.49)	1.50 (0.80)	1.77 (1.69)	1.71 (1.56)	2.43 (2.80)

NSP, neutral scapular position; RSP, retracted scapular position; PSP, protracted scapular position.
Significant differences between scapular positions: RSP-PSP difference, + $P < 0.05$, ++ $P < 0.01$.
Significant differences between scapular elevation conditions: x $P < 0.05$, xx $P < 0.01$, xxx $P < 0.001$.

Table 3
UT/SA activity ratio recorded during shoulder abduction movement with the scapula in neutral, retracted and protracted position, and with or without scapular elevation. Data reported as mean (standard deviation).

Shoulder abduction angle	Without scapular elevation			With scapular elevation		
	NSP	RSP	PSP	NSP	RSP	PSP
15	2.48 (1.75)$^{°°°,\ xxx}$	4.85 (4.30)$^{+++}$	2.30 (1.35)^{xxx}	5.35 (3.73)	5.53 (3.86)	4.36 (2.50)
30	2.11 (1.59)$^{°°°,\ xxx}$	3.89 (2.99)$^{+++}$	2.30 (1.68)^{xxx}	4.07 (2.12)	4.30 (2.96)	3.56 (1.64)
45	1.74 (1.29)$^{°°°,\ xxx}$	3.09 (2.18)$^{+}$	2.21 (1.89)^{xx}	3.51 (1.96)	3.69 (2.90)	3.06 (1.36)
60	1.41 (0.92)$^{°°,\ xxx}$	2.44 (1.58)	1.87 (1.41)^{xx}	3.00 (1.76)	3.14 (2.31)	2.58 (1.14)
75	1.26 (0.84)^{xxx}	1.97 (1.17)	1.55 (1.00)^{x}	2.47 (1.47)	2.56 (2.03)	2.23 (1.00)
90	1.11 (0.79)^{xx}	1.65 (0.91)	1.26 (0.74)^{x}	2.10 (1.32)	2.08 (1.55)	1.80 (0.82)
105	1.01 (0.65)^{x}	1.46 (0.77)	1.02 (0.51)^{x}	1.78 (1.10)	1.70 (1.14)	1.54 (0.73)
120	0.90 (0.53)	1.31 (0.63)	0.88 (0.38)	1.43 (0.69)	1.50 (0.92)	1.33 (0.63)

NSP, neutral scapular position; RSP, retracted scapular position; PSP, protracted scapular position.
Significant differences between scapular positions: NSP-RSP difference, °° $P < 0.01$, °°° $P < 0.001$; RSP-PSP difference, + $P < 0.05$, +++ $P < 0.001$. Significant differences between scapular elevation conditions: x $P < 0.05$, xx $P < 0.01$, xxx $P < 0.001$.

conditions (Contemori & Biscarini, 2017; Cools et al., 2007). The imbalance between the UT and the other trapezius portions may actually hamper the optimal scapulohumeral rhythm, predisposing the shoulder to acute or overuse injuries. Therefore, upper limb rising movements that promote low UT/MT and UT/LT ratios are probably safer than those that cause high UT activation.

Without scapular elevation, the SA activity was higher in protracted scapular position than in neutral and retracted position, whereas the SA was less active when participants actively elevated the shoulder (Fig. 7), leading to high UT/SA ratio (Table 3). During shoulder abduction the UT and SA act synergistically to upwardly rotate the scapula. However, the increase of UT activation due to shoulder elevation could influence the scapular upward rotation. Of interest, in a recent work, Turgut demonstrated that stronger UT causes increased scapular upward rotation during shoulder abduction (Turgut, Duzgun, & Baltaci, 2016). The higher UT activation actually increases its force output, thus it is possible to assume that when the UT is more active the scapular upward rotation is sustained mainly by the UT, with consequent less need of SA activation.

A high UT/SA activity ratio has previously been found in pathologic shoulders conditions, such as impingement syndrome and infraspinatus muscle atrophy (Contemori & Biscarini, 2017; Cools et al., 2007). Shoulder abduction movements that lead to an imbalance between the UT and SA could potentially affect the optimal scapulohumeral rhythm, hampering the optimal shoulder girdle function, and thus may represent a risk factor for shoulder injuries. Given that, shoulder abduction should be performed without shoulder elevation, in order to promote a better balance between the ST muscles.

Despite the interesting findings, we must acknowledge some limitations of this study. The absence of scapular kinematic data represents the main limitations. Actually, the retraction and protraction positions, as well as scapular elevation, could change the offset angle of scapular upward/downward rotation, internal/external rotation, and anterior/posterior tilt, affecting the activity of the shoulder girdle muscles. Moreover, the muscle activation recorded during shoulder abduction in different combinations of scapular position and scapular elevation may affect the scapular kinematics during the movement. Therefore, future research studies should be conducted in order to assess the scapular kinematics during these movements, since it represents a critical factor for the optimal functioning of the shoulder complex. Another limitation is represented by the lack of information about the activity of posterior deltoid. Actually, in all the selected scapular positions the humerus was always elevated in the plane of the scapula, and the MD is the prime mover for the shoulder abduction in the scapular plane as it posses grater mechanical advance to abduct the shoulder than posterior deltoid. However, information about the posterior deltoid activity would have provided a more complete

understanding of the potential effects of scapular position and scapular elevation on the activity of the shoulder girdle muscles. Finally, some of the main effects and interactions that reached statistical significance resulted in moderate effect size levels. This likely comes from the considerable variability of the EMG recordings during both the abduction tasks and MVIC tests, that is common in EMG studies involving dynamic exercises. This leads to higher values of *sum of squares for error* in the partial eta squared computation.

5. Conclusions

Overall, the results of this study offer a map of the different activation patterns that can be adopted by the analyzed muscles, suggesting important motor control strategies of integrating a common shoulder movement with various modification of the scapular position. Specifically, this study highlights the effects of scapular protraction and scapular elevation on the increased activity of the MD during shoulder abduction, with potential risks for fault GH arthrokinematics and consequent subacromial impingement. Moreover, the present study has pointed out that scapular protraction and scapular elevation lead to increased UT activity, concurrently with reduced activity of the MT and LT. This suggests the existence of specific reciprocal inhibition effects between the movers and stabilizers muscles of ST joint. These patterns of activation also result in high ratios between the UT and the other muscles that act on the scapula, which is a common finding in a number of shoulder girdle pathologies. Exploration of these patterns of activation may enhance understanding of motor control mechanism of the shoulder, and has direct implication for preventive and clinical interventions since it gives important new information about the type of movements that could endanger the optimal function of the shoulder.

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