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Kinetic chain influences on upper and lower trapezius muscle activation during eight variations of a scapular retraction exercise in overhead athletes

Kristof De Mey [a,*], Lieven Danneels [a], Barbara Cagnie [a], Van den Bosch Lotte [b], Flier Johan [b], Ann M. Cools [a]

[a] *Department of Rehabilitation Sciences and Physiotherapy, University Hospital, Belgium*
[b] *Private Practice, The Netherlands*

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Abstract

Objectives: To describe and compare the activation levels of the upper and lower trapezius muscle and study the influence of trunk and lower extremity position or movement during eight variations of a scapular retraction exercise.
Design: Descriptive study. Exercise performance was standardized and individualized based on height, age and body weight.
Method: Individual muscle activation was captured by surface electromyography in thirty young healthy overhead athletes. Exercises were performed in front of a pulley apparatus.
Results: The mean values for upper trapezius and lower trapezius were 6.59% and 15.93% of maximum voluntary isometric contractions respectively. Main effects were found for "exercise" ($F = 2.60$; $p = 0.037$) and "muscle part" ($F = 25.44$; $p < 0.001$) in an ANOVA for repeated measures model showing higher lower trapezius muscle activation compared to the upper trapezius across exercises. An unipodal squat position on the contralateral leg increased trapezius muscle activation by 3.93% maximum voluntary isometric contraction ($p = 0.019$) compared to the conventional seated performance of the exercise. No differences between phases were found and no exercise activated a particular muscle part (upper trapezius or lower trapezius) to a greater extent in comparison with other exercises since no two-way interactions were found with $p < 0.05$.
Conclusion: All exercise variations may be useful in the early phases of scapular rehabilitation training because of their favorable trapezius muscle balance activation. Standing in a squat position on the contralateral leg can result in a slight increase in trapezius muscle activation. However, future comparative effectiveness studies are needed to identify the long-term training benefits of these exercises.

Keywords: Scapula; Trapezius; Exercises; Electromyography; Kinetic chain

1. Introduction

Scapular dyskinesis and related shoulder impingement syndrome are common conditions, particularly in overhead athletes.[1] Although various muscles contribute to the three-dimensional movements around the shoulder, a lack of activity in the lower trapezius (LT) has been observed in these people, often in combination with an excessive upper trapezius (UT) activation.[2] This might contribute to excessive clavicle elevation on the thorax coupled with increased anterior tilt at the scapulothoracic joint which causes the rotator cuff to impinge during elevation.[3] The UT and LT muscles play different roles around the scapula during dynamic activities. Whereas the UT does not appear to have a line of action for being a substantive upward rotator in healthy persons, the LT assists in producing scapulothoracic upward rotation.[4] Furthermore, evidence indicates that the LT acts as a stabilizer at the scapulothoracic joint.[4] Consequently, scapular muscle exercises characterized by high LT and low UT

* Corresponding author.
E-mail address: Kristof.demey@ugent.be (K. De Mey).

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muscle activation are of interest in the rehabilitation of patients with secondary impingement.

Training the activation and strength of selective muscle parts is the most common clinical approach in the management of musculoskeletal disorders. Depending on different stages of rehabilitation, various exercises might improve scapular muscle performance. In general, rowing and scapular retraction exercises have been found to enhance scapular muscle performance because of their preferential trapezius muscle activation.[5–7] In addition, the scapular retracted position has been found to reduce symptoms and increase muscle performance in patients with impingement symptoms.[8,9]

Recent guidelines have pointed to the value of integrating shoulder girdle exercises into a global functional kinetic chain for multiple reasons.[10,11] In general, these recommendations are based on the principle of sport specificity emphasizing the core as the center of the body during upper extremity training. Furthermore, it is assumed to increase the activity in particular shoulder muscles compared to more artificially stabilized positions such as the prone, side-lying or seated position. Maenhout et al. have recently investigated the influence of the position of the lower extremity on scapular muscle activity and balance during closed kinetic chain push-up variations.[12] In their research, they discovered that contralateral leg extension stimulates LT activity during a knee push up plus exercise. However, the influence of proximal body segments during scapular retraction exercises integrating the trunk and lower extremity has not yet been investigated. Therefore, the purpose of this study was to analyze UT and LT muscle activation levels in an overhead athletic population during eight variations of a high scapular retraction movement. It was hypothesized that differences between UT and LT muscle activation would be found in all exercises and that the kinetic chain, influenced by lower extremity position or movement, would have an effect on these activation levels.

2. Methods

The data were obtained from a group of 30 healthy overhead athletes (17 male, 13 female), including volleyball and tennis players, and swimmers (mean ± SD age, 20 ± 3.5 years; mean ± SD weight, 69.4 ± 10.5 kg; mean ± SD body height, 179 ± 0.11 cm; mean ± SD BMI, 22 ± 0.02). The participants were recruited from the student population in the local metropolitan area. Twenty-seven were right-handed and 3 were left-handed, and it was the dominant shoulder that was tested. Athletes were included if they were between 18 and 30 years old and were able to perform the exercises correctly. People were excluded if they had a history of glenohumeral instability, shoulder surgery, or if they currently exhibited symptoms related to the spine or structural injuries to the shoulder complex. Athletes engaged in an upper limb strength training program for more than 5 h per week were also excluded in order to avoid interference from specific adaptations. Inclusion and exclusion criteria were assessed by means of a questionnaire. All participants gave their written informed consent to participate in this study, which was approved by the Ethical Committee of Ghent University Hospital.

After the athletes had completed a warm-up consisting of shoulder movements in all directions and push ups against the wall, the skin was shaved and prepared with alcohol in order to reduce skin impedance (typically ≤ 10 kΩ). Bipolar surface electrodes (Blue Sensor – Medicotest, Denmark) were then placed with a 2 cm inter-electrode distance over the UT and LT muscle parts of the dominant shoulder. Electrodes for the UT were attached midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius. The LT electrode was placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process. A reference electrode was placed over the clavicle of the dominant shoulder. To ensure consistency with electrode placement, all electrodes were put into position by one researcher. Each set of bipolar recording electrodes from the eight muscles was connected to a Noraxon Myosystem 1400 electromyographic receiver (Noraxon USA, Inc., Scottsdale, AZ). The sampling rate was 1000 Hz and all raw myo-electric signals were preamplified (overall gain = 500, common mode rejection ratio 115 dB, signal to noise ratio < 1 μV RMS baseline noise).

First, the resting level of the electrical activity of each muscle was recorded. Then, maximum voluntary isometric contraction (MVIC) was determined in manual muscle test positions that were specific to both muscles of interest. For the UT, resistance was applied to abduction of the arm from a seated position. For LT testing in a prone position, the arm was placed diagonally overhead in line with the lower fibers of the trapezius and resistance was applied against further elevation. Participants performed three 5-s MVICs against manual resistance by the researcher. A 5-s pause occurred between muscle contractions. A metronome was used to control the duration of the contractions. After rectification, electrocardiogram reduction and smoothing, the average electromyographic (EMG) value over a window of 2 s was calculated for each trial. Further calculations were performed with the mean of the repeated trials as a normalization value (100%).

After MVIC testing, there was a 5-min resting period for each participant. Then, each person conducted a series of eight scapular retraction exercises in a randomized order in front of a pulley apparatus. The exercises are presented in Table 1 and Figs. 1 and 2. All angles were verified using a goniometer. All exercises were performed at 1 m in front of the pulley apparatus. The height was adjusted to be at head level of each participant depending on the participant's posture. Participants carried out the retraction movement starting from a scapular protracted position. Each exercise was performed until the elbow was positioned at the lateral side of the trunk. The athletes were instructed to maintain neutral spinal

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Table 1
The 8 variations of the high scapular retraction exercise.

High scapular retraction exercise	Variation	Description
1	Sitting	Trunk supported and feet positioned on the ground
2	Standing	Feet positioned shoulder width and legs straight
3	Static bipedal squat	Feet placed shoulder width with both knees positioned at a 90° angle above the feet
4	Static lunge	Contralateral leg in front with the knee in a 90° angle. Distance between both feet individually determined by taking the distance between the ASIS and the medial malleolus of the dominant side
5	Static unipedal squat	Contralateral knee placed above the foot in a 45° angle
6	Dynamic bipedal squat	Starting position as static version. Concentric phase of arm movement during concentric squat
7	Dynamic lunge	Starting position as static version. Concentric phase of arm movement during concentric lunge
8	Dynamic unipedal squat	Starting position as static version. Concentric phase of arm movement during concentric squat

Table 2
Pulley resistance (in kg) applied to the subjects (age in years).

Age	Male			Female		
	Subject weight			Subject weight		
	50–59 kg	60–69 kg	70–85 kg	50–59 kg	60-69 kg	70–85 kg
18–20	7	8	9	5	6	7
21–23	8	9	10	6	7	8
24–26	9	10	11	7	8	9
27–30	10	11	12	8	9	10

alignment. A neutral grip was applied during each exercise. The contralateral hand was placed at the anterior superior iliac spine for feedback concerning neutral pelvis alignment. Before data collection, the exercises were demonstrated by one of the researchers. Then, the participant first carried out the exercises without resistance in order to become familiar with the exercise, receiving corrective feedback as needed. Five trials of each exercise were completed. Between trials, a relative resting period of 3 s was provided. The participants were allowed to rest for 2 min between exercises. Each exercise was executed in three phases (concentric, isometric and eccentric), each lasting 3 s. A metronome was used to

Fig. 1. High scapular retraction exercise variations (1, sitting; 2, standing; 3, static bipedal squat; 4, static lunge).

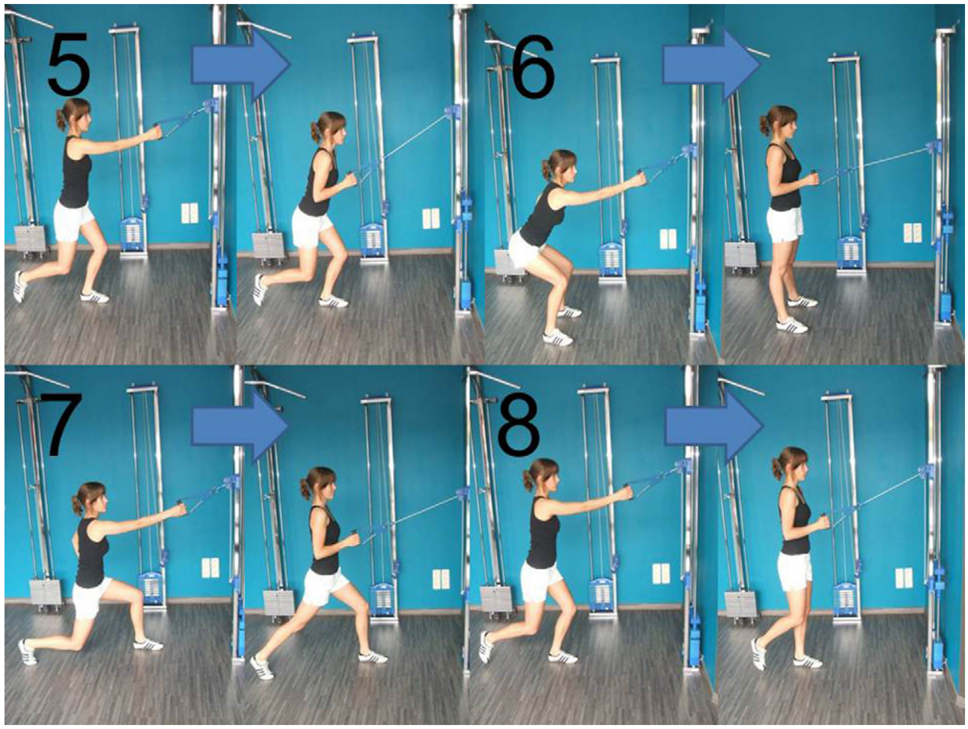

Fig. 2. High scapular retraction exercise variations (5, static unipedal squat; 6, dynamic bipedal squat; 7, dynamic lunge; 8, dynamic unipedal squat).

control the duration of the phases. During each exercise, the same examiner encouraged the participants verbally and, if necessary, corrected their performance. During EMG measurement, synchronized video recordings were made with a Sony Handycam (DCR-HC 37) to control duration of phases. Participants were divided into genders, age and into three subgroups based on their weight for resistance determination. (Table 2). Within each participant, the same load was used for all postures.

All raw EMG signals were analog/digital converted (12-bit resolution) at 1000 Hz and markers were placed at the beginning of each phase. After cardiac artifact reduction, rectification and smoothing (root mean square = 100 ms), the EMG activity during 2 s after the markers was calculated for each muscle and each phase. Then, the total muscular activity across the different phases was determined by calculating the mean activity of the second, third and fourth repetition of each exercise. The first and last repetitions were not used for further analysis in order to avoid any distortion due to habituation and fatigue. All data were analyzed by the Myoresearch 98 Software Program®.

All statistical analyses were performed with the Statistical Package for the Social Sciences, version 16.0 for Windows (SPSS Inc., Chicago, IL). Means and standard deviations were calculated across participants for normalized EMG activity during all exercises. Because a Kolmogorov–Smirnov test showed normal distribution of the data, parametric tests were used for statistical analysis.

ANOVA for repeated measures with the within-participant factors "exercise" (8 levels), "muscle part" (2 levels) and "phase" (3 levels) was used to determine whether there were any differences between exercises in EMG amplitudes for each muscle. A .05 α level was chosen a priori to denote statistical significance for these comparisons. For any significant difference, a Bonferroni post hoc analysis was used to denote significance for follow-up analysis.

3. Results

Means and standard deviations were calculated across participants for normalized EMG activity of each muscle for all exercises (Table 3). The ANOVA model revealed that sphericity could not be assumed, and a Greenhouse–Geisser correction was used to interpret all results. No three-way interaction was found with $p < 0.05$. Subsequently, two-way interactions including the factor "exercise" were of interest, but none of them showed significant results. So, in none of the exercises the muscle activation was significantly different between phases, and none of the exercises activated a particular muscle part (UT or LT) to a greater extent compared to the other. However, main effects were identified for "exercise" ($F = 2.60$; $p = 0.037$) and "muscle part" ($F = 25.44$; $p < 0.001$). Pair-wise comparisons were performed with Bonferroni post hoc correction for multiple comparisons with significant differences between (1) muscle parts across exercises and (2) exercises across muscle parts. The mean values for UT and LT amounted to 6.59% and 15.93% of MVIC, respectively. Lower trapezius showed significantly higher muscle activation across exercises compared to UT with a

Table 3
Means and standard deviations for normalized EMG activity of UT and LT for each phase of all exercise.

Exercise phase	UT			LT		
	1	2	3	1	2	3
Sitting	4.84 ± 0.72	7.32 ± 1.23	5.23 ± 0.85	14.10 ± 2.01	13.93 ± 1.79	11.76 ± 2.57
Standing	5.14 ± 0.65	6.59 ± 0.92	4.24 ± 0.55	18.34 ± 2.96	18.49 ± 2.17	8.04 ± 1.64
SBS	5.61 ± 0.60	7.09 ± 0.89	7.33 ± 1.02	20.76 ± 4.51	17.32 ± 2.53	15.40 ± 2.51
SL	5.82 ± 0.93	7.62 ± 1.21	4.83 ± 0.67	18.54 ± 2.31	15.98 ± 2.34	12.24 ± 3.45
SUS	6.63 ± 0.89	8.45 ± 1.23	6.13 ± 0.84	21.89 ± 4.23	17.37 ± 2.80	20.27 ± 4.93
DBS	7.00 ± 0.99	7.24 ± 1.19	8.41 ± 1.13	19.50 ± 4.00	15.41 ± 2.16	12.01 ± 2.11
DL	6.27 ± 0.86	7.98 ± 1.01	5.78 ± 0.71	16.04 ± 1.87	17.30 ± 2.34	9.80 ± 1.90
DUS	7.17 ± 1.04	8.68 ± 1.42	6.79 ± 0.89	17.50 ± 2.69	15.80 ± 2.46	14.44 ± 2.51

Values expressed as mean percentage of maximum voluntary isometric contraction ± standard deviation (UT, upper trapezius; LT, lower trapezius; 1, concentric phase; 2, isometric phase; 3, eccentric phase of each exercise; SBS, static bipedal squat; SL, static lunge; SUS, static unipedal squat; DBS, dynamic bipedal squat; DL, dynamic lunge; DUS, dynamic unipedal squat).

mean difference of 9.34% MVIC ($p < 0.001$). Standing in an unipedal squat position on the contralateral leg resulted in a significantly higher trapezius muscle activation compared to the conventional seated performance of the exercise (mean difference = 3.93% MVIC; $p = 0.019$).

4. Discussion

Particular retraction exercise variations might have an influence on the recruitment patterns of specific shoulder muscles. However, the conventional focus on individual joint training has resulted in a limited knowledge of scapular muscle recruitment during exercises that activate the entire kinetic chain system. Therefore, we investigated UT and LT muscle activation during eight kinetic chain variations of a high scapular retraction exercise which is thought to be relevant in the rehabilitation of scapular dyskinesis and related impingement symptoms. The main findings of this study were that all exercises recruit LT over UT muscle activation and that a contralateral single squat position stimulates higher trapezius muscle activation levels.

With respect to the first finding, the results support the notion that all exercises might be effective in treating scapular neuromuscular dysfunctions in athletes struggling with a decreased control of LT in combination with excessive UT activation.[13,14] Several researchers have tried to select exercises with high LT muscle activation, some of which studied scapular retraction or rowing exercises in non-lying positions starting from different arm positions.[15] In general, LT activity has been found to be relatively low at angles less than 90° of scapular abduction and flexion, with exponential increases from 90° to 180°.[15] More particularly, Bressel et al. showed the LT to be most active during the performance of a scapular retraction movement at 130° of shoulder elevation in a seated position.[16] Andersen et al. found the LT to be predominantly activated over the UT during a one-arm row exercise performed in a bend position resulting in an unknown amount of arm elevation.[17] Additionally, a recent paper of Wattanaprakornkul et al. has shown similar results during a row exercise performed in sitting on a gym equipment with constant resistance.[18] However, the amount of forward flexion during their exercises was probably too low to result in statistically different activation levels between both muscle parts. Similarly, McCabe et al. could not find differences between UT and LT while people performed a scapular retraction exercise at an 80° degree forward flexion angle.[19] In our study, the pulley apparatus was set at head level depending on the participant's posture, resulting in a forward flexion position of more than 90° in each participant. Probably, this could clarify why, in our study, the LT was recruited over the UT during all exercises.[20]

Mean UT and LT muscle activations were below 20% MVIC in our study. According to McCan et al., our values should be considered minimal, as moderate activation levels require 21–50% MVIC and marked activation levels > 50% MVIC.[21] Some other studies found higher values. In an EMG analysis for resistance-tubing exercises for throwers, Myers et al. found moderate activation (defined as > 20% of MVIC) during unilateral high retraction exercises performed in a standing position with mean LT values of 51.2% MVIC.[6] McCabe et al. found marked activity in both the LT (51 ± 29% MVIC) and UT (50 ± 36% MVIC) during a scapular retraction exercise.[19] Similarly to our results, Hintermeister et al. found average amplitudes of 9.2% and 7% MVIC in the trapezius muscle during a seated rowing exercise depending on the applied load. Rather low values for UT and LT (between 4.99% and 18.73% MVIC) were also found by Cools et al. in some of the phases during a high rowing exercise. Although they could not select high rowing as an optimal exercise for rehabilitation of scapular muscle balance based on low UT/LT ratio data, these values suggest the exercises to be useful in retraining neuromuscular control rather than strength training of the trapezius muscle.[22] However, it should be noted that comparing the results of different studies has limited value, since differences in specific exercise prescriptions, load determination and normalization techniques vary between studies.

Recent guidelines have strongly promoted the use of kinetic chain exercises throughout the rehabilitation program rather than starting with exercises that isolate the shoulder and then gradually incorporate the rest of the body.[23] With respect

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to our second finding, namely that an unipedal squat position on the contralateral leg increases trapezius muscle activation, the results are in line with previous evidence of kinetic chain influences on shoulder muscle activation during medical exercise training. Maenhout et al. found an 8.82% MVIC increase of LT activation influenced by contralateral lower extremity position during a knee push up plus exercise.[12] They recorded minimal changes in the activation levels caused by proximal kinetic chain influences, which might be relevant, since the scapulothoracic joint almost solely depends upon muscle activity for its functional stability.[24] In our study, a small difference of 3.93% was found. Up till now, no research has established a cut off for EMG activity (%EMG) to be considered clinically important when comparing multiple exercises. Although a 10% difference in muscle activation might be needed in terms of muscle strengthening purposes, no such a value is available in the literature with regard to neuromuscular training.[25] In addition, there is still an ongoing debate on how to define clinical relevance in relation to statistical data.[26] Therefore, the clinical benefit of the unipedal squat exercise remains unknown until comparative effectiveness studies are presented in the literature. Interestingly, none of the upright exercises resulted in an increased UT muscle activation without altering the LT muscle when comparing the data with those of the seated exercise. This justifies all exercise variations to be useful in the transition from easy to more challenging types of rehabilitation. Moreover, the use of kinetic chain scapular retraction exercises may also be suited for other training purposes than influencing specific shoulder muscle activation since they promote the integration of the scapular retraction movement to the hip. These motions tend to be coupled in the cocking phase of throwing, which indicates the relevance of adding lower extremity movements to the scapular retraction exercise.[27]

Myofascial structures connecting the shoulder, trunk and lower extremity have been identified and might serve as a potential underlying mechanism to explain proximal kinetic chain influences on scapular muscle recruitment.[12,28] However, as specific physiological evidence for its effectiveness has not yet been described, other possible underlying explanations should not be ruled out when interpreting our results. For example, the maintenance of a static unipedal squat position throughout the different phases of the exercise could also explain the difference found between both exercises since this might have resulted in minimal changes in joint position, length–tension relationships, movement of skin over the muscles and consequently in acquisition of EMG activity signals from different motor units.[29] Additionally, it should be taken into account minimal spinal rotations could have occurred in some participants, resulting in slightly higher trapezius activation levels during the unipedal squat exercise. Although not monitored by three-dimensional analysis, this was minimized by constantly instructing the participants to keep neutral spinal alignment.

Some limitations considering this study need to be addressed. First, the use of surface EMG during dynamic contractions has been a topic of discussion in the literature regarding skin displacement, movement artifacts, influences of contraction type on the EMG signal and normalization methods.[30,31] Second, we did not capture the activation of other muscles, such as the middle trapezius, rhomboid major and serratus anterior, which limits the interpretation in terms of force-couple and co-contraction behavior. Third, the use of young healthy overhead athletes limits the generalization of the results to older people and patients with impingement symptoms.

The results of our study also provide a basis for future research. First, the additional use of three-dimensional analysis would give information on the relationship between joint kinematics and neuromuscular parameters. The influence of proximal posture and stability on upper extremity muscle recruitment could also be a topic of interest. Second, synergistic activation of shoulder, trunk and lower extremity muscles could be investigated during various exercises by using the coactivation method.[32] Third, short- and long-term effects, including various relative loads and the use of instruction, demonstration and extrinsic feedback could be performed in both healthy athletes and patients with secondary impingement.

5. Conclusion

In view of the recent tendencies with respect to functional kinetic chain training, we investigated UT and LT muscle activation during a series of eight variations of the high scapular retraction exercise. The results show higher LT compared to UT muscle activation in all exercises. We can conclude that standing in a squat position on the contralateral leg stimulates higher trapezius muscle activation levels compared to a seated performance of the exercise suggesting kinetic chain influences on the shoulder muscle activation level. However, further research is required in order to substantiate the clinical relevance of these findings.

6. Practical implications

- Scapular retraction exercises seem useful for trapezius neuromuscular coordination training in overhead athletes because of their low upper trapezius muscle activation levels compared to those of the lower trapezius muscle.
- Several kinetic chain variations might be useful because none of them result in excessive upper trapezius activation in healthy athletes.

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