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Original article

Serratus anterior or pectoralis minor: Which muscle has the upper hand during protraction exercises?

Birgit Castelein [a, *], Barbara Cagnie [a], Thierry Parlevliet [b], Ann Cools [a]

[a] Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Sciences, University Hospital, Ghent, Belgium
[b] Department of Physical Medicine and Orthopedic Surgery, University Hospital, Ghent, Belgium

A R T I C L E I N F O

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A B S T R A C T

Background: The Serratus Anterior (SA) has a critical role in stabilizing the scapula against the thorax. Research has linked shoulder and neck disorders to impairments in the SA activation. Exercises that target the SA are included in the rehabilitation of shoulder or neck pain and mostly include a protraction component. The Pectoralis Minor (PM) functions as a synergist of the SA. From the literature it is unclear to what extent PM is activated during SA exercises.
Objectives: To determine the activity of SA and PM during different protraction exercises.
Design: Controlled laboratory study.
Method: 26 subjects performed 3 exercises: Modified Push-Up Plus (Wall Version), Modified Knee Push-Up Plus (Floor version) and Serratus Punch. Electromyographic (EMG) data was collected from the SA (surface) and PM (fine-wire EMG).
Results: During the Serratus Punch the SA activity was significantly higher than the PM activity. During the Modified Push-Up Plus exercises (both Wall and Floor version), the SA and PM activity were comparable. The PM showed the highest activity during the Serratus Punch and the Modified Push-Up Plus (Floor), which was significantly higher than during the Modified Push-Up Plus (Wall). The SA showed the highest activity during the Serratus Punch, which was significantly higher than during the Modified Push-Up Plus (Floor) which was in turn significantly higher than the activity during the Modified Push-Up Plus (Wall).
Conclusions: All exercises activated the PM between 15 and 29% Maximum Voluntary Isometric Contraction and the SA between 15 and 43%. The Modified Push-Up Plus exercise against the wall and the floor activated the SA and PM to a similar degree. When maximum activation of the SA with minimal activation of the PM is desired in healthy subjects, the "Serratus punch" seems to be the optimal exercise.

1. Introduction

Among the muscles attached to the scapula, the Serratus Anterior (SA) muscle has a critical role in stabilizing the scapula against the thorax (Lear and Gross, 1998; Smith et al., 2003). Additionally, SA contributes to all components of the movement of the scapula during elevation of the arm: upward rotation, protraction and external rotation[1] (Lear and Gross, 1998). Research has linked shoulder and neck disorders to impairments in the activation of the SA muscle (weakness, fatigue, timing problems) (Glousman et al., 1988; Scovazzo et al., 1991; Wadsworth and Bullock-Saxton, 1997; Ludewig and Cook, 2000; Helgadottir et al., 2011; Sheard et al., 2012; Larsen et al., 2013). Therefore, various exercises that target the SA are included in the rehabilitation of patients with shoulder or neck pain (Moseley et al., 1992; Andersen et al., 2014; De Mey et al., 2014; Piraua et al., 2014).

Exercises that have been prescribed to predominantly activate the SA mostly include a protraction component. Push-Up exercises are known to be one of the most effective exercises for activating the SA. The Push-Up exercise is a closed kinetic chain exercise performed in a prone position by raising and lowering the body using the arms. Studies showed that the "plus-phase" of the Push-Up exercise shows the highest SA activation as compared with

* Corresponding author. University Hospital Ghent, Department of Rehabilitation Sciences and Physiotherapy, De Pintelaan 185, 3B3, B9000 Ghent, Belgium.
E-mail address: Birgit.Castelein@ugent.be (B. Castelein).

[1] Different authors cited in the article use different terminology for same movements: i.e. for scapular rotations: upward (lateral or external)/downward (medial or internal) rotation, anterior/posterior tilt and internal/external rotation. Protraction/retraction and elevation/depression are often described as movements of the clavicle (Helgadottir et al., 2010).

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other SA activation exercises (Decker et al., 1999; Ludewig et al., 2004). The "plus-phase" involves posterior translation of the thorax on relatively fixed scapulae, which can be done alone or along with push-ups (Hardwick et al., 2006). Ludewig et al. (2004) suggested that the SA was selectively activated to a greater extent in "Push-Up Plus" than in standard Push-Up exercises. Different modifications on the Push-Up Plus exercises are commonly used in clinical practice: Push-ups can be performed either on the floor ("Floor Push-Up Plus") or against the wall ("Wall Push-Up Plus"), supported on elbow ("Elbow Push-Up Plus"), or hands or feet or knee ("Knee Push-Up Plus"). Alternatively, the "Serratus Punch" (=performing protraction in open kinetic chain) is an exercise that is also often used to activate the SA (Escamilla et al., 2009; Liebenson, 2012).

The Pectoralis Minor (PM) functions as a synergist of the SA. Both the SA and the PM engage in the protraction movement of the scapula. From the literature it is unclear to what extent PM is activated during SA exercises. Apart from the protraction movement, the PM also causes, downward rotation, depression and anterior tilting of the scapula (Oatis, 2004). Overuse of this PM might result in adaptive shortening of the muscle. A shortened PM has been identified as a risk factor that contributes to abnormal scapular positioning (Tate et al., 2012). When PM lacks extensibility the scapula is anteriorly tilted and internally rotated (Borstad, 2008), which may lead to the development and perpetuation of upper limb symptoms (rounded shoulder posture, glenohumeral joint dysfunction, subacromial impingement) (Borstad, 2008; Lynch et al., 2010; Wong et al., 2010; Tate et al., 2012; Struyf et al., 2014). Clinical theories (Borstad and Ludewig, 2005; Ludewig and Reynolds, 2009; Cools et al., 2014b) suggest that motor strategy favoring activity in PM over SA is thought to be detrimental. So when performing exercises that include a protraction movement aiming to activate the SA, it is important to know the influence of that exercise on the activation of the PM.

Several studies have investigated SA activity during different SA exercises (Moseley et al., 1992; Decker et al., 1999; Ludewig et al., 2004; Maenhout et al., 2010; De Mey et al., 2014; Park et al., 2014; Piraua et al., 2014). However, to date, no study has investigated the PM activity when protraction exercises are performed nor compared SA and PM activity. One study of Moseley et al. (1992) investigated SA and PM activity during 2 protraction exercises: "Push-Up with hands apart" and "Push-Up with a Plus". They found these 2 exercises optimal (>50% maximum manual muscle strength test) for both SA and PM, but did not compare muscle activity between muscles or exercises. Moreover, they did not concentrate on the plus-phase, but on the whole exercise. Consequently, EMG investigations are necessary in order to address this current deficit in our knowledge regarding the muscle balance between the SA and PM during exercises that are thought to activate the SA.

Therefore, the purpose of this study was to investigate the EMG activity of the PM and the SA during 3 protraction exercises: (a) the "Modified Push-Up Plus" (Wall Version) (b) the "Modified Knee Push-Up Plus" (Floor Version) and (c) the "Serratus Punch".

2. Methods

2.1. Subjects

Twenty-six subjects (15 female, 11 male, mean age 33.3 ± 12.4, ranging from 21 to 56 years old, weight 67.1 ± 9.2 kg, height 174.2 ± 8.2 cm) participated in this study. The choice for the sample size was based on previous research in that area, that investigated differences in SA activity between exercises (Decker et al., 1999; Ludewig et al., 2004; Hardwick et al., 2006; De Mey et al., 2014; Park et al., 2014; Piraua et al., 2014) and that investigated both SA and PM activity (Moseley et al., 1992). Descriptive characteristics of the subject group can be found in Table 1. All subjects were free from current or past shoulder or neck pain and demonstrated full pain-free range of motion of both shoulders. They did not perform overhead sports nor upper limb strength training for more than 6 h/week. Investigation of the in- and exclusion criteria was performed by a clinical expert with several years of experience. Written informed consent was obtained from all participants. The study was approved by the ethics committee of X.

2.2. General design

EMG data was collected from the SA and the PM on the dominant side of each subject during the performance of the Modified Push-Up Plus (Wall Version), the Modified Knee Push-Up Plus (Floor version) and the Serratus Punch.

2.3. Test procedure

The experimental session began with a short warm-up procedure with multidirectional shoulder movements, followed by the performance of the maximum voluntary isometric contractions (MVIC) of the muscles of interest. These data are needed for normalization of the EMG signals. A set of different isometric MVIC test positions was completed to allow normalization of the EMG data (Castelein et al., 2015). These consisted of the following:

1. "Abduction 90°" (sitting)
2. "Horizontal Abduction with external rotation" (prone lying)
3. "Arm raised above head in line with Lower Trapezius (LT) muscle fibers" (prone lying)
4. "Shoulder flexion 135°" (sitting)
5. "Arm raised above head in line with PM muscle fibers" (supine lying)

All MVICs were performed prior to the exercises, except for the MVIC "Arm raised above head in line with PM muscle fibers". This MVIC was performed in supine lying and was always performed at the end (after the exercises) to avoid pressure on the electrodes of the dorsal muscles (due to their contact with the examination table because of the supine position) until all exercises were performed. Each MVIC test position was performed 3 times (each of the contractions lasted for 5 s-controlled by a metronome) with at least 30 s rest between the different repetitions. There was a rest period of at least 1.5 min between the different test positions. Manual pressure was always applied by the same investigator and strong and consistent encouragement from the investigator was given during each MVIC to promote maximal effort. Before data collection, MVIC test positions were taught to each subject by the same investigator, and sufficient practice was allowed.

In the second part of the investigation, the subject performed 5 repetitions of 3 different exercises (Table 2). The exercises were performed randomly. Before data collection, the subject was given a visual demonstration of each exercise by the investigator. Each exercise consisted of a concentric protraction phase of 3 s and an

Table 1
Descriptive characteristics of the subjects.[a]

	Women	Men	Total
N	15	11	26
Age (years)	31.9 ± 12.8	35.3 ± 12.4	33.3 ± 12.4
Weight (kg)	62.7 ± 7.3	73.2 ± 7.6	67.1 ± 9.2
Height (cm)	169.2 ± 6.2	181.0 ± 4.6	174.2 ± 8.2

[a] Data reported as mean ± Standard deviation (SD).

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Table 2
Description of the exercises.

Name	Description of the exercise	Figure
Modified Push-Up Plus (Wall version)	Participant standing in front of the wall, on a distance that is determined by the length of the forearm plus one big step. The hands are placed on the wall on shoulder width with the participants hands pointed to the ceiling The arms are parallel to the floor. The starting position is in maximal scapular retraction. From this position, the patient rolls the shoulders forward (scapular protraction) during 3 s and then lowers the body during 3 s while allowing the shoulder blades to approximate (scapular retraction). The elbows are in full extension during the whole exercise and the head is kept in-line with the trunk and vertebral column.	
Modified Knee Push-Up Plus (Floor version)	Participant taking place on a bench, with support on knee and hands. The hands are placed on shoulder width with the subjects hands under the acromioclavicular joint. The arms are perpendicular to the floor. The head, trunk and knees are in one line. The starting position is in maximal retraction. From this position, the patient rolls the shoulders forward (scapular protraction) during 3 s and then lowers the body while allowing the shoulder blades to approximate (scapular retraction). The elbows are in full extension during the whole exercise and the head is kept in-line with the trunk and vertebral column. During the test, the subject looks at the floor with no cervical rotation, flexion, or extension.	
Serratus punch	Participant standing with the back to the pulley apparatus (1 m), with the shoulder in 90° of forward flexion. The starting position is a scapular retracted position. The participant performs scapular protraction with elbow extended (3 s protraction – 3 s retraction). The subjects maintains neutral spinal alignment, and does not rotate or lean forward. The contralateral hand is placed at the anterior superior iliac spine for feedback concerning neutral pelvis alignment. *The amount of load of the pulley resistance is determined based on sex and body weight. For female subjects, the dumbbell load is always 2.5 kg (independent of the weight of the subject), whereas in male subjects the load is allocated according to the weight of the subject (7 kg, 8 kg or 10 kg for respectively 60–69 kg, 70–79 kg and 80–89 kg). This approach was based on results from a pilot study.	

eccentric retraction phase of 3 s. A metronome was used to control and standardize the velocity speed of the movement (60 beeps/min). When the participants were able to perform the proper movement pattern and timing of the exercise, EMG data were collected from 5 repetitions of each exercise with 5 s of rest in between each trial. Between each exercise set, a break of 1.5 min was provided.

2.4. Instrumentation

A TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ) was used to collect the EMG data. Bipolar circular surface electrodes (Ag/AgCl, Ambu® Blue Sensor, Medicotest, Type N-00-S 30 × 22 mm, Ballerup, Denmark) were used to collect EMG data from the SA. They were placed with a 1 cm interelectrode distance over the SA, according to the to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) Project Recommendations (Hermens et al., 2000; Cools et al., 2007; De Mey et al., 2009; Maenhout et al., 2010). A reference electrode was placed over the spinous process of C7 vertebrae. Before surface electrode application, the skin surface was shaved, cleaned and scrubbed with alcohol to reduce impedance (<10 kOhm). Intramuscular paired-hook fine-wire electrodes (Carefusion Middleton, WI, USA – wire length 125 mm) were used to measure the EMG activity of the PM. They were inserted into the muscle belly on the midclavicular line to the anterior surface of the third rib (according to the locations described by Delagi et al. (1994) using a single-use 25-gauge hypodermic needle). This was done using real-time ultrasound guidance, which has been shown to be an accurate and repeatable method of intramuscular electrode placement (Hodges et al., 1997). The surface and intramuscular electrodes were looped and taped on the skin to prevent them from being accidentally removed during the experiment and to minimize movement artifacts. The sampling rate was 3000 Hz. All raw myo-electric signals were preamplified (overall gain = 1000, common mode rejection ratio of 100 dB, baseline noise < 1 μV root-mean-square).

2.5. Signal processing and data analysis

The Myoresearch 3.4 Master Edition Software Program was used for signal processing. The EMG signals were filtered with a high pass Butterworth filter of 20 Hz. Cardiac artifact reduction was performed, followed by rectification and smoothing (root mean square, window 100 ms) of the signals. The EMG data for each muscle and each participant was averaged for each exercise across the 3 intermediate repetitions of the 5 repetitions completed. The first and fifth repetitions were not used to control for distortion due to habituation or fatigue. These EMG data were normalized and expressed as a percentage of their MVIC. For each MVIC, the average EMG value was calculated over a window of the peak 2.5 s of the 5 s. The average of the 3 trials was used for normalization. All MVIC test positions were analyzed for each muscle (except the PM activity was not analyzed during prone lying MVIC test positions). The normalization value (100%) was the highest value for that muscle recorded during the MVIC tests.

2.6. Statistical analysis

SPSS 22.0 was used for statistical analysis. Means ± standard deviations were calculated for the normalized EMG values (in % of MVIC). A linear mixed model was applied to determine if there were significant differences in EMG activity between "muscles" (SA, PM) and "exercises" ("Modified Push-Up Plus" (Wall Version), "Modified Knee Push-Up Plus" (Floor Version) and the "Serratus Punch") and "gender". The residuals of the linear mixed models were checked for normal distribution. Post-hoc pairwise comparisons were performed using a Bonferroni correction. An alpha level of 0.05 was applied to all the data in determining significant differences.

3. Results

Results of the Linear Mixed Models are shown in Table 3.

The Linear Mixed Model showed a significant muscle*exercise ($p < 0.002$; $F = 7468$, $df1 = 2$, $df2 = 261{,}496$) and muscle*phase ($p < 0.001$; $F = 31{,}369$, $df1 = 1$, $df2 = 260{,}241$) interaction effect. No gender difference was detected for the EMG data. The mean muscle EMG activity for the PM and SA during each exercise (the Serratus Punch, the Modified Push-Up Plus (Wall Version) and the Modified Knee Push-Up Plus (Floor version)) is provided in Fig. 1. Regarding the muscle*exercise interaction effect, post-hoc tests revealed an increased RMS EMG activity of 15.8% for the SA compared to PM during the Serratus Punch ($p < 0.002$). During the Modified Push-Up Plus (both Wall and Floor version), the amount of SA activity and PM activity were comparable, and did not differ significantly from each other. When comparing the muscle activity between the exercises, the PM showed the highest activity during the Serratus Punch and the Modified Push-Up Plus (Floor version), and this was significantly higher than during the Modified Push-Up Plus (Wall Version) ($p = 0.002$ and $p < 0.001$). The SA showed the highest activity during the Serratus Punch, which was significantly higher than during the Modified Push-Up Plus (Floor Version) ($p < 0.001$) which was in turn significantly higher than the activity during the Modified Push-Up Plus (Wall version) ($p < 0.001$).

Regarding the muscle*phase interaction effect, post-hoc tests showed that during the concentric phase of the protraction exercises, the SA activity was significantly higher than the PM activity ($p < 0.001$). Also, the SA showed significantly higher activity during the concentric phase in comparison with the eccentric phase of the protraction exercises ($p < 0.001$). Mean (±SD) muscle EMG activity of the PM and SA during each phase (concentric and eccentric) of the exercise is provided in Table 4.

Table 3
Results of statistical analysis of the different main factors and interaction effects. Statistical significance was accepted at $p < 0.05$.

Effects	Significance of corresponding p-value
Muscle*exercise*phase*gender	Not significant
Exercise*phase*gender	Not significant
Muscle*phase*gender	Not significant
Muscle*exercise*gender	Not significant
Muscle*exercise*phase	Not significant
Muscle*exercise	**Significant**
Muscle*phase	**Significant**
Exercise*gender	Not significant
Muscle*gender	Not significant
Phase*gender	Not significant
Exercise*phase	Not significant
Exercise	Significant
Muscle	Significant
Phase	Significant
Gender	Not significant

4. Discussion

Patients with shoulder and neck pain are often recommended to include exercises that focus on SA in their rehabilitation program. From a clinical point of view, it is of interest what the role of the PM is during the performance of these protraction exercises. Exercises that highly activate the SA muscle while minimizing activation in the PM are generally preferred. To our knowledge, this is the first study to compare the muscle activity of the SA and the PM during protraction exercises.

The main finding of the study was that the Serratus Punch exercise seems the best exercise when the aim is to highly activate the SA with minimum activation of the PM. The Modified Push-Up Plus exercises, both in floor and wall version, did activate the PM and the SA to a similar extent. When only focusing on the concentric phase of the exercises, the SA was significantly more activated than the PM in all exercises.

The SA activity during the "Serratus Punch" was found to be the highest of the three exercises. This result is in agreement with previously published research. Cools et al. (2014a) also found that the "Serratus punch" elicited higher activity of the SA in comparison with the "Knee Push-Up Plus". The amount of EMG activity is also in line with the results from Cools et al. (2014a) and Decker et al. (1999). Cools et al. (2014a) found an EMG activity of the SA of 42.7 ± 15.49% MVIC during "Serratus Punch", while our study found an EMG activity of 42.9 ± 16.1% MVIC. For the "Knee Push-Up Plus", our study found an SA EMG activity of 30.3 ± 14.8%MVIC which is in line with the results of Cools et al. (2014a) (37.0 ± 18.12% MVIC) and Decker et al. (1999) (for the protraction phase 42.1 ± 15.4%MVIC and for the retraction phase 35.2 ± 12.7% MVIC). In addition, the "Serratus Punch" was the only exercise in which the activity of the PM was significantly lower than that of the SA, which meets the criteria of good PM/SA ratio. Despite this good PM/SA ratio (significantly lower PM activity than the SA) it should be noted that the PM is more activated in comparison with the Modified Push-Up Plus wall version (see Fig. 1). Another advantage of the Serratus Punch is that it is performed in a standing position, which is a very functional position, contrary to the positions of the other exercises. The Modified Push-Up Plus wall version showed the lowest PM EMG activity. The Serratus Punch and the Modified Push-Up Plus exercises differ in their performance: the Serratus Punch can be seen as an open kinetic chain exercise, while the Push-Up Plus is a closed kinetic chain exercise. In case of the open kinetic chain, the arm is moving relative to the thorax, which could be one of the reasons why SA is working more in comparison with the PM. This is in contrast with the closed kinetic chain exercises, in which the thorax is moving relative to the arm. In these closed kinetic chain exercises, the SA and PM work to the same extent.

We believe that these results and recommendations can help clinicians in the choice of exercises for scapular rehabilitation. These Push-Up Plus exercises can be used in treatment of scapulothoracic muscle imbalance. Janda describes muscle imbalance as an impaired relationship between muscles prone to facilitation and muscles prone to inhibition (Jairus Quesnele, 2011). However, new theories state that imbalance between muscle activity is redistributed within and between muscles, rather than stereotypical inhibition or excitation of muscles (Hodges, 2011). They state that muscle activity can be variable with the objective to "protect" the tissue from further pain or injury. This strategy has short-time benefit, but with potential long-term consequences due to factors

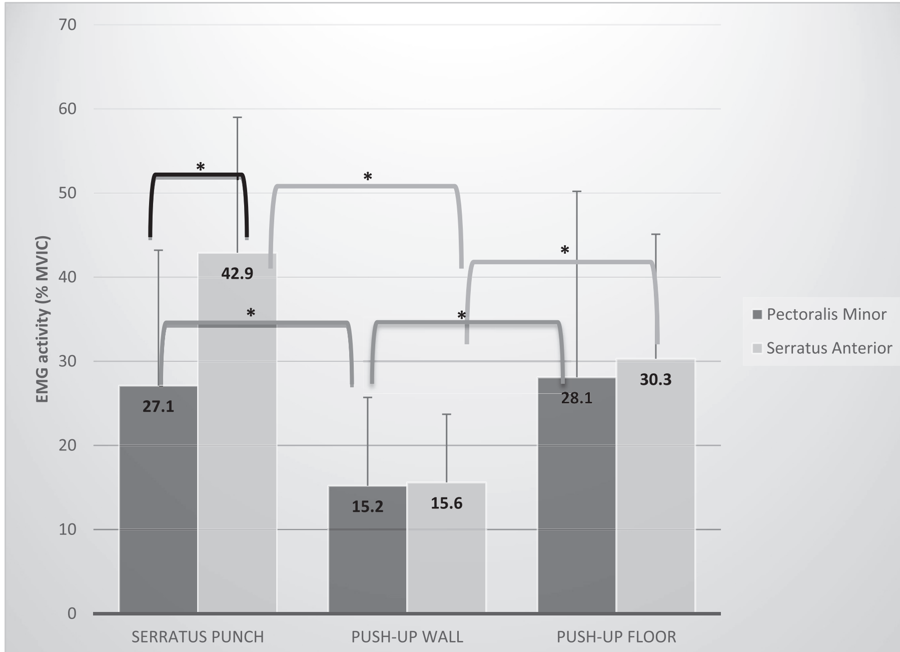

Fig. 1. EMG activity (%MVIC ± SD) of the Pectoralis Minor and Serratus Anterior during Serratus Punch, Modified Push-Up Plus Wall Version (Plus Wall) and Modified Push-Up Plus Floor version (Plus Floor), * = $p < 0.05$.

Table 4
EMG activity (% MVIC ± SD) of the Pectoralis Minor and Serratus Anterior during each phase (concentric and eccentric) of each exercise.

	Concentric phase		Eccentric phase		Whole movement	
	Pm activity	SA activity	Pm activity	SA activity	Pm activity	SA activity
Serratus punch	23.0 ± 13.8	51.5 ± 21.1	29.5 ± 17.3	32.0 ± 13.8	27.1 ± 16.1	42.9 ± 20.2
Modified Push-Up Plus Wall version	13.5 ± 9.7	21.0 ± 10.8	16.8 ± 11.9	10.1 ± 6.8	15.2 ± 10.9	15.2 ± 10.5
Modified Push-Up Plus Floor version	27.9 ± 21.4	39.7 ± 19.6	28.3 ± 24.0	21.0 ± 12.3	28.1 ± 22.5	30.3 ± 18.8

as increased load, decreased movement, and decreased variability. The PM and SA are both agonists (for protraction), but also antagonists (SA: upward and external rotation – PM: downward and internal rotation). According to Janda's approach, the PM is part of the tonic system muscles which is prone to tightness or shortness, whereas the SA is part of the phasic system muscle which is prone to weakness or inhibition. Sherrington's law of reciprocal inhibition states that a hypertonic antagonist (PM) muscle may be reflexively inhibiting the agonist (SA) (Sherrington, 1907). Therefore, in the presence of overactive or tight antagonistic muscles, restoring normal muscle tone/activation must first be addressed before attempting to activate a weakened or inhibited muscle. In clinical practice, scapular rehabilitation often starts with stretching of the PM in order to address the adaptive shortening and to reposition the scapula (Ellenbecker and Cools, 2010; Lynch et al., 2010). This is followed by training of the scapular stabilizing muscles. However, sometimes the benefit of these interventions remains unsatisfactory. A possible reason for this recurrence could be that, notwithstanding the fact that the PM is stretched to reposition the scapula, the adaptive shortening of the PM can possibly return because of activation of this muscle during scapular exercises. Overactivation of the PM results in malaligned scapula as it pulls the scapula anteriorly. An anteriorly tipped position of the scapula brings the scapular stabilizing muscles in a lengthened position and this affects their ability to control scapular position at rest as well as during motion (McClure et al., 2012; Tate et al., 2012; Kibler et al., 2013). The nature of this dysfunction impacts on the type of exercise required to restore this stabilizing or supporting role. Therefore it is important to choose the appropriate exercises when the goal is to activate the SA.

Although the exercises did not lead to a high activation of the PM (all protraction exercises activated the PM between 15 and 29% MVIC), we still believe it is recommended to take these results into account when making decisions for rehabilitation. The Push-Up Plus exercises can be used with increasing level of challenge. Since fatigue is a predisposing factor to compensated movement patterns, endurance is more important than absolute strength of the muscles. Endurance of the muscles is increased through repetitive, coordinated exercises at low intensities and high volumes.

Some limitations should be taken into account when interpreting the results of this study. A first limitation of this study is the comparison of surface EMG data from the SA with fine wire EMG data from the PM. Nevertheless, other studies have also compared surface EMG results with fine-wire EMG results in the shoulder region (Boettcher et al., 2010; Wickham et al., 2010; Wattanaprakornkul et al., 2011). Additionally, a difference in workload for the two genders was used in this study for the Serratus Punch exercise. The workload for this exercise was determined based on a pilot study to define the appropriate weight for performing 3 sets of 10 repetitions. This difference in load might influence the motor strategy of men and women although this was not shown in the statistical analysis (Table 3), but the analysis might have been underpowered to identify a possible difference. Nevertheless, a similar approach for determining workload has previously been used in other studies too (Cools et al., 2007, 2014a).

Third, it is a limitation that we did not measure the distance to the wall for each of the participants when performing the Modified Push-Up Plus Wall version. Nevertheless, we believe that the method " the length of the forearm plus one big step" did not lead to differences in shoulder angles between the different participants that would significantly affect the results. Additionally, as we only collected data after the participants had shown ability to perform proper movement and timing of the exercise, it is a limitation that there might have been a difference in how much training each subject received to get this movement and timing correct. Another limitation is the lack of kinematic data during the protraction exercises in our study. It should also be noted that extrapolation of the results to other population groups should be performed with caution. Furthermore, we should note that although our results show that the Modified Push-Up Plus versions on the floor and on the wall lead to an activation of both the SA and PM in a similar degree, no proof has been given that training with Modified Push-Up Plus exercises effectively leads to overactivity of the PM and to compensation patterns. Some further investigations might be interesting to perform. The influence of other muscles, such as the Pectoralis Major during these protraction exercises could be of interest. The Pectoralis Major is known to be in close relationship with the PM, as it also attaches to the anterior chest wall. As this muscle is also often too active, it might be relevant for future research to investigate the muscle activation during these exercises (Park et al., 2014). The study could also be repeated with a group of patients suffering from shoulder or neck pain. Subsequently, comparing the results of that study with the current investigation could be relevant because this would give more insight into how the pain condition impacts the muscle recruitment during each exercise.

5. Conclusion

PM and SA activity were investigated during different exercises that focus on SA activation (Serratus Punch, Modified Push-Up Plus Wall version, Modified Push-Up Plus Floor version). All exercises activated the PM between 15 and 29% MVIC and the SA between 15 and 42%MVIC. The Modified Push-Up Plus exercises against the wall and the floor activated the PM to a similar degree as the SA. When maximum activation of the SA with minimal activation of the PM is desired in healthy subjects, the "Serratus punch" seems to be the optimal exercise.

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