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Scapular Muscle Rehabilitation Exercises in Overhead Athletes With Impingement Symptoms

Effect of a 6-Week Training Program on Muscle Recruitment and Functional Outcome

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Background: Previous research has identified some specific exercises to correct scapular muscle balance and onset timing in healthy subjects. However, evidence for their effectiveness in overhead athletes with impingement symptoms has been lacking until now.

Hypothesis: A 6-week exercise program consisting of previously selected exercises is able to improve muscle activation and onset timing during shoulder elevation. This program may also change pain and functionality levels in overhead athletes with mild impingement symptoms.

Study Design: Case series; Level of evidence, 4.

Methods: Forty-seven overhead athletes with mild impingement symptoms (25 men and 22 women) were enrolled in this study. Before and after the 6-week training program, the Shoulder Pain and Disability Index (SPADI) score was individually obtained and maximum voluntary isometric contraction (MVIC) values were determined by surface electromyography. Mean muscle activation levels, muscle ratio data, and muscle onset timing were assessed for the upper (UT), middle (MT), and lower (LT) trapezius and serratus anterior (SA) muscle during arm elevation in the scapular plane.

Results: Forty participants completed the exercise program. The SPADI scores significantly decreased from 29.86 $\pm$ 17.03 during initial assessment to 11.7 $\pm$ 13.78 during postmeasurements ($P < .001$). The 3 trapezius muscle parts showed increased MVIC values and decreased activation levels during arm elevation, whereas this was not the case for the SA muscle. After the training program, UT/SA significantly decreased, whereas UT/MT and UT/LT did not change ($P < .05$). No differences in muscle timing between pre- and postmeasurements could be identified. The LT showed significant earlier activation compared with UT (−0.47; $P < .001$) and MT (−0.49; $P < .001$). The serratus anterior showed significant earlier activation compared with the UT (−0.74; $P < .001$), MT (−0.76; $P < .001$), and LT muscles ($F = 0.27$; $P = .046$).

Conclusion: This is the first longitudinal study to demonstrate that previously selected exercises (1) improve pain and function based on SPADI scores, (2) reduce relative trapezius muscle activation, and (3) alter UT/SA ratios. However, they were unable to change the timing of the scapular muscles during arm elevation when compared before and after a 6-week training program in overhead athletes with mild impingement symptoms.

Keywords: scapula; impingement; training; electromyography

Shoulder impingement symptoms are very common in athletes participating in sports with overhead arm motions. They are associated with a wide range of underlying mechanisms and injuries such as scapular dyskinesis, posterior shoulder stiffness, rotator cuff tendinopathy, and glenohumeral instability.[8] Although the origin is considered multifactorial, overuse is one of the main causes of symptom development.[47] In most cases, the diagnosis is made after the athlete has stopped training because of aggravating pain levels and functional limitations. Therefore, resistance training exercises over the full range of motion with

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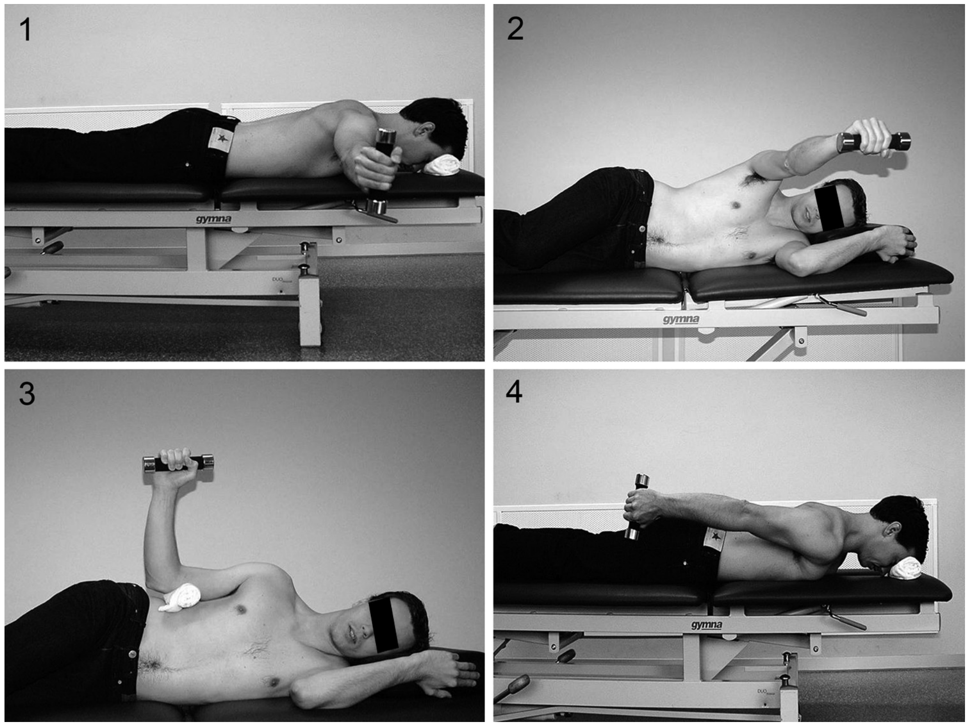

Figure 1. Four selected exercises performed daily during 6 weeks. The order was altered each week (week 1: 1, 2, 3, 4; week 2: 4, 3, 2, 1; week 3: 1, 4, 2, 3; week 4: 4, 1, 3, 2; week 5: 1, 3, 2, 4; week 6: 4, 2, 3, 1).

considerable load are an inappropriate treatment strategy at that moment.[4,18] However, a significant number of athletes experience pain but have not yet stopped training or contacted the team physician and, as a result, do not experience time loss due to their injury.[4,23] In these athletes with less severe, mild symptoms, a resistance training program might be useful to prevent their complaints from becoming a chronic condition.[9,38]

Impingement symptoms typically exacerbate when the arm is elevated or when overhead throwing activities are performed.[29,43] During these movements, scapular dyskinesis is a major contributor of impingement symptom development, as recent literature has indicated.[35] Alterations in scapular muscle performance have been found in subjects with scapular dyskinesis. Hyperactivity of the upper trapezius (UT) with reduced middle (MT) and lower trapezius (LT) muscle activation in addition to insufficient serratus anterior (SA) muscle function has been related to decreased amounts of scapular upward rotation, external rotation, and posterior tilt in patients.[41] Furthermore, some authors have found a delayed onset of scapular muscle activation between patients with and without symptoms.[12,56] These findings suggest that timing of muscle activation is another important factor in the relationship between the dynamic muscular actions and the scapular kinematics.

According to recent review articles, exercise training alleviates symptoms in patients with impingement.[36,37] The current evidence indicates that therapeutic exercise is more effective in reducing pain and improving function than placebo in both short- and long-term follow-up and more effective than no intervention in short-term follow up.[43] Several studies have examined the muscle activation patterns of various resistance exercises that focus on improving scapular muscle recruitment.[22,37,48] In the rehabilitation process of shoulder impingement, exercises focusing on selective activation of weaker muscle parts with minimal activity in the hyperactive ones are an important component. Recently, Cools et al[11] selected 4 exercises to rehabilitate the scapular muscle balance based on low UT/MT and UT/LT ratios in healthy subjects: (1) side-lying forward flexion, (2) side-lying external rotation, (3) prone horizontal abduction with external rotation, and (4) prone extension in neutral position (Figure 1). In a later study, De Mey et al[14] revealed early MT and LT muscle activation when compared with the UT during side-lying external rotation, prone horizontal abduction with external rotation, and prone extension. They speculated that these exercises might alter the timing of the scapular muscles during dynamic activities. However, none of these studies has investigated the potential effect on the pain, function, and recruitment pattern of the scapular musculature during arm elevation. In addition, most studies have investigated the effect of exercise in relation to other treatment modalities such as manual therapy, corticosteroid injection, or radial extracorporeal shockwave, making it impossible to evaluate the beneficial effect of exercise in isolation.[20,30,36,37] Therefore, the aim of this study was to evaluate the effect of the 4 exercises in a clearly defined population of overhead athletes with mild impingement symptoms. It was hypothesized that after a 6-week exercise program containing these exercises, all subjects would experience pain reduction and improved functionality accompanied by a change in muscle activation levels and onset timing during shoulder elevation. The results of this trial could add evidence to the limited body of knowledge on the effect of physical therapy in patients with shoulder impingement symptoms.

MATERIALS AND METHODS

Subjects

Forty-seven subjects participated in this study (25 men and 22 women), with a mean (SD) age of 24.6 (7.81) years, an average weight of 72.55 (11.45) kg, and an average height of 178.48 (7.98) cm with a body mass index (BMI) of 22.70 (2.68). They spent a mean of 6 hours a week playing competitive overhead sports, including volleyball (17), tennis (10), canoe polo (2), baseball (2), swimming (11), and badminton (5). The subjects' mean (SD) sporting experience was 6 (1.5) years. Subjects were recruited over 2 seasons: 2010-2011 and 2011-2012. None of them had stopped training or contacted the team physician for their complaints, so they did not experience any time loss due to their injury.[4] Forty-three subjects were right-handed and 4 were left-handed. In 2 subjects, the nondominant side was affected. All athletes had shoulder impingement symptoms for at least 3 months. Shoulder impingement was diagnosed on the basis of previous research and clinical examination.[10,12] The latter consisted of positive Neer, Hawkins, Jobe, apprehension, and relocation testing. Subjects were included if they met at least 2 of the following 5 criteria: (1) positive Neer sign: reproduction of pain when the examiner passively flexed the humerus to end range with overpressure; (2) positive Hawkins sign: reproduction of pain when the shoulder was passively placed in 90° of forward flexion and internally rotated to end range; (3) positive Jobe's sign: reproduction of pain and lack of force production with isometric elevation in the scapular plane in internal rotation; (4) pain with apprehension: reproduction of pain when an anteriorly directed force was applied to the proximal humerus in the position of 90° of abduction and 90° of external rotation; and (5) positive relocation: reduction of pain after a positive apprehension test when a posteriorly directed force was applied to the proximal humerus in the position of 90° of abduction and 90° of external rotation. No subjects were included in the study based on the last 2 criteria alone. It was thought that patients with minor instability and secondary impingement would experience pain but no apprehension during these tests. In addition, only subjects with altered scapular resting positions and dyskinesis were included. This was determined on the basis of dynamic clinical examination using a simple yes/no method.[55] A "yes" means the clinician states that an abnormal dyskinesis pattern is observed. Uhl et al[55] demonstrated that this method has a sensitivity and positive predictive value of 76% and 74%, respectively, when compared with the results of a 3-dimensional analysis. Subjects were excluded if they had a dislocation, had undergone shoulder surgery, or exhibited symptoms related to the cervical spine. They were not retained for this study either if they were currently taking nonsteroidal anti-inflammatory medications, received a steroid injection in the past 12 months, did not reach full range of motion during shoulder elevation (end range pain was allowed), or were already enrolled in a physical therapy program. The study was approved by the Ethical Committee of the Ghent University Hospital, and all subjects gave their written consent to participate.

Exercise Program

The subjects were tested before and after a 6-week daily home exercise program consisting of the exercises presented in Table 1. Recent literature has demonstrated that home exercises may be as effective as supervised exercises.[36,37] In our study, a 6-week training period was used because the most significant improvement was expected in this time period.[21] In addition, it was assumed a daily home exercise program consisting of only 4 exercises should not be performed over a longer period because of motivational issues. According to a recent review article, 6 weeks of training is in line with the current recommendations for exercise training studies.[37] Before starting the program, the athletes were thoroughly instructed in the 4 exercises by a physical therapist, and illustrations with specific exercise instructions were provided, as well as a compliance log. All subjects performed the exercises with the affected side on a daily basis. Three sets of 10 repetitions for each exercise were prescribed, with a 1-minute rest between sets. Initial exercise weights were determined based on gender and body weight but were further individualized by 10 repetition maximum (RM) testing.[11] Pain up to a visual analog scale (VAS) pain level of 5 was allowed during 10 RM testing, although only in the case that the pain subsided immediately after the exercise was completed. Sporting activities were allowed during the whole training program, but no additional upper limb strength training was permitted. To monitor progress, ensure correct movement pattern, and control load progression, the subjects were either seen in the clinic or followed up by telephone by the physical therapist at 2 and 4 weeks of training. Progression of exercises was decided on the basis of the same criteria as were used during initial instructions. Subjects experiencing higher pain levels (above 5 on a VAS scale) could reduce their weight accordingly. To minimize repetitive overload, the order of the exercises was altered each week. Such type of planned variation is generally recommended by the American College of Sports Medicine to ensure efficient gains in response to strength training.[1]

Testing Procedure

Pre- and posttesting was performed in the same setting, with the same standardized examination protocol, assessment methods, and testing equipment. Initial data collection occurred on the day the exercises were provided. First, the Shoulder Pain and Disability Index (SPADI) score was individually obtained by the same researcher. The SPADI is a valid and reliable self-administered questionnaire, is quick to complete, and does not change

TABLE 1
The 4 Previously Selected Exercises Used in the 6-Week Exercise Program

Exercise	Description
Prone extension	The subject is prone with the shoulders resting in 90° of forward flexion. From this position, the subject performs bilateral extension to a neutral position with the shoulder in neutral rotation.
Forward flexion in side lying	The subject is in a side-lying position, with the shoulder in neutral. The subject performs 90° of unilateral forward flexion in a sagittal plane.
External rotation in side lying	The subject is side lying with the shoulder in neutral position and the elbow flexed 90°. From this position, the subject performs 90° of external rotation of the shoulder with a towel between the elbow and trunk to avoid compensatory movements.
Prone horizontal abduction with external rotation	The subject is prone with the shoulders resting in 90° of forward flexion. From this position, the subject performs bilateral horizontal abduction to a horizontal position, with an additional external rotation of the shoulder at the end of the movement.

significantly in stable subjects.[45,49] Higher scores indicate a greater level of pain and disability (0-100). The SPADI has been shown to be valid and very responsive in assessing shoulder pain and function, and it is therefore highly recommended for use in patients with impingement.[7] Second, in line with previous studies, bipolar surface electrodes (Blue Sensor; Medicotest, Ølstykke, Denmark) were placed with a 2-cm interelectrode distance over the UT, MT, LT, and SA of the subject's dominant shoulder.[11] If necessary, the skin was shaven and further preparation was performed with alcohol to reduce skin impedance (typically ≤10 kOhm). A reference electrode was placed at the ipsilateral clavicle. To ensure consistency with electrode placement, all electrodes were placed by 1 researcher. The electrodes were then connected to a 16-channel Noraxon Myosystem 2000 electromyographic receiver (Noraxon USA, Inc, Scottsdale, Arizona). The researcher confirmed that the electrodes were correctly placed by inspecting the electromyography (EMG) signals on a computer screen during specific muscle testing. The sampling rate was 1000 Hz. All raw myoelectric signals were preamplified (overall gain = 1000, common rate rejection ratio 115 dB, signal-to-noise ratio <1 μV root mean square [RMS] baseline noise). Subsequently, the researcher verified the quality of the EMG signal for each muscle by having the subject perform maximal voluntary isometric contractions (MVIC) in manual muscle test positions specific to each muscle of interest[33,52] (see Appendix 1, available in the online version of this article at http://ajs.sagepub.com/supplemental/). Subjects performed three 5-second MVICs against manual resistance from the researcher. A 5-second pause occurred between muscle activations, and a metronome was used to control the duration of muscle activities. With the objective to minimize the influence of pain on the MVIC, subjects reporting pain during testing were excluded. After rectification, electrocardiogram (ECG) reduction, and smoothing, the peak average EMG value over a window of 2 seconds was calculated for each trial. Further calculations were performed with the mean of the repeated trials as a normalization value (100%).

After MVIC testing, subjects were allowed to rest for 5 minutes. Then, they each performed bilateral arm elevation in the scapular plane (30° anterior to the coronal plane) during 3 phases (concentric, isometric, and eccentric) that each lasted 3 seconds (Figure 2). This was practiced until reliable reproduction of the movement was achieved at the required velocity. Subjects completed 5 trials of this movement, with 3 seconds of rest between each trial. Isometric readings were taken at maximal elevation. With the EMG registration, simultaneous video recordings were made and a metronome was used to control the duration of phases (Sony Handycam, DCR-HC 37; Sony USA, New York, New York). To ensure minimal basic resting level on the EMG recording, arm elevation was performed without any resistance.

Data Analysis

All EMG signals were processed by means of the 98 Myoresearch software program (Noraxon, Scottsdale, Arizona). The raw EMG signals were analog-digital converted (12-bit resolution) at 1000 Hz. After rectification, cardiac artifact reduction, and smoothing, both the average EMG activation of the different muscle parts and the timing of the scapular muscle activation were determined. Mean muscle activation was then normalized according to the MVIC method. This was done by calculating the mean activity of the second, third, and fourth repetitions of each trial. The first and last repetitions were not used for further analysis to avoid the influence of habituation and fatigue. Muscle ratios UT/MT, UT/LT, and UT/SA were also calculated. To determine muscle onset timing, only the concentric phase was used for further analysis. As the time of muscle activity initiation, we used the point at which the activity levels in the muscles reached 2 standard deviations above the resting activity with a minimum of 50 ms.[27] Muscle onset times were then analyzed relative to the onset time of the posterior deltoid.[14] Each muscular event as determined by the onset algorithm was visually inspected by a researcher to ensure muscular onset validity.[15]

Statistical Analysis

The sample size for this study was based on a minimal relevant difference of 10% in EMG findings and an expected

Figure 2. Performing elevation of the arm in the scapular plane.

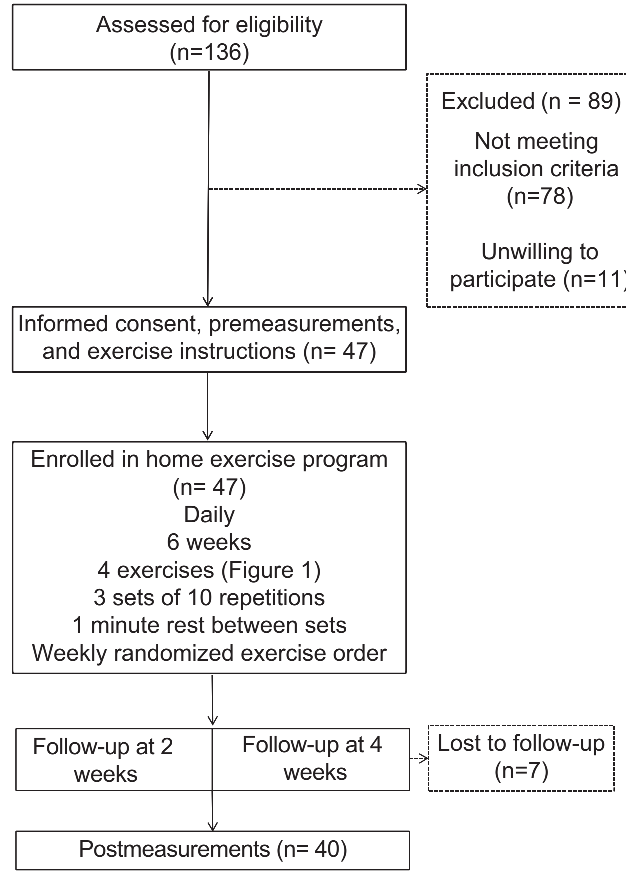

Figure 3. Flow diagram of the study.

14-point reduction of the SPADI score to be significant at the 5% level, resulting in a statistical power of 80%. Based on the results of other studies, the assumed standard deviation was set to 10% in EMG measurements and 20 points of the SPADI score.[2,60] A 15% dropout rate was expected. With the objective to study the influence of reamplifying surface electrodes on the normalized EMG values, the MVICs were determined in a separate group of 25 healthy subjects. Surface electrodes were reamplified after 1 week without intervention, and the between-session reliability was calculated.

All statistical analyses were performed with the Statistical Package for the Social Sciences, version 18.0 for Windows (SPSS Inc, Chicago, Illinois). Means and standard deviations were calculated across subjects for the results of the normalized EMG activity and the timing of each muscle. Muscle ratio data (UT/MT, UT/LT, and UT/SA) and SPADI scores were also calculated.

Because a Kolmogorov-Smirnov test showed normal distribution of the data with $P < .05$, parametric tests were used for statistical analysis. Subsequently, paired t tests were performed to detect differences in the SPADI scores between pre- and posttesting. Statistical significance was accepted at an α level of .05. Analysis of variance (ANOVA) for repeated measures with the within-subject factors "time" (2 levels = pre- and posttesting), "muscle" (4 levels = 4 muscles), and "phase" (3 levels = concentric, isometric, and eccentric) was used to determine whether there were any differences between pre- and posttesting for the normalized EMG activity for each muscle during each phase of arm elevation. The same was done for the UT/MT, UT/LT, and UT/SA ratios. Because differences in timing between muscle parts at the beginning of arm movement were also of interest, an ANOVA for repeated measures was used with within-subject factors "time" (2 levels = pre- and posttesting) and "muscle" (4 levels = 4 muscles). An α level of .05 was chosen a priori to denote statistical significance for these comparisons. For any significant difference, a Bonferroni post hoc test to denote significance was used for follow-up analysis.

RESULTS

Forty subjects completed the exercise program (Figure 3). Seven subjects dropped out of the study, 4 because of private reasons and 3 because of aggravating pain levels. From the 40 subjects who completed the exercise program, 12 were followed up by telephone only. These subjects were contacted more frequently, focusing on guidance to facilitate appropriate performance of the exercises. Completed daily exercise logs were returned in 68% of the subjects. The

TABLE 2
Mean Electromyographic Activity During Maximum Voluntary Isometric Contraction Measurements Before and After the 6-Week Exercise Program[a]

	Before Program, Mean (SD)	After Program, Mean (SD)	Difference, Mean (95% CI)	*P* Value
UT	512.64 (400.02)	741.22 (440.63)	−228.58 (−374.21 to −82.95)	.003
MT	427.77 (273.23)	542.11 (356.97)	−114.34 (−213.95 to −14.72)	.026
LT	482.58 (308.12)	639.59 (351.76)	−157.01 (−257.77 to −56.26)	.003
SA	496.03 (357.65)	547.74 (430.89)	−51.71 (−148.38 to 44.95)	.285

[a]Means are expressed in millivolts. CI, confidence interval; LT, lower trapezius; MT, middle trapezius; SA, serratus anterior; UT, upper trapezius.

SPADI scores significantly decreased from 29.86 ± 17.03 during initial assessment to 11.7 ± 13.78 during postmeasurements ($P < .001$). Seven patients achieved a SPADI score of zero during postmeasurement.

The paired tests revealed that the 3 trapezius muscle parts exhibited increased MVIC values when compared before and after the exercise program (Table 2). Considering the normalized EMG activities, the ANOVA model revealed a 3-way interaction ($F = 2.74$, $P = .43$) with post hoc tests showing decreased activation levels in the trapezius muscle during arm elevation, whereas this was not the case for the SA ($P < .05$) (Appendix 2, available online). The UT was the only muscle showing decreased activation levels during each phase of the movement. For the scapular muscle ratios, no 3-way interaction was found ($F = 1.22$; $P = .307$). However, a 2-way interaction of time × ratio could be demonstrated ($F = 6.33$; $P = .005$), with post hoc tests revealing that, without differences between phases, UT/SA significantly decreased after the training program, whereas UT/MT and UT/LT did not change ($P < .05$) (Appendix 3, available online). Considering muscle timing, no significant 2-way interaction was found ($F = 0.44$; $P = .69$). However, a significant main effect for "muscle" was presented ($F = 30.38$; $P < .001$), indicating that the timing of muscle activation differed between muscle parts but not between pre- and postmeasurements. Consequently, the lower trapezius showed significantly earlier activation compared with the UT (−0.47; $P < .001$) and MT (−0.49; $P < .001$), whereas SA showed significantly earlier activation compared with the UT (−0.74; $P < .001$), MT (−0.76; $P < .001$), and LT ($F = 0.27$; $P = .046$) when combining the results of the pre- and postmeasurements (Figure 4).

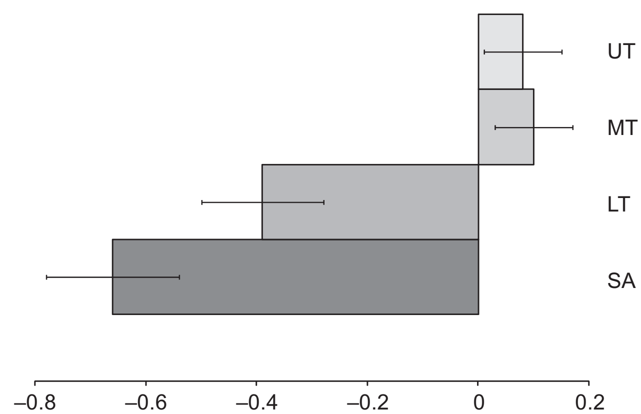

Figure 4. Schematic representation (means and standard deviations) of the timing of muscle activation of the upper (UT), middle (MT), and lower (LT) trapezius and serratus anterior (SA) relative to the timing of the posterior deltoid (PD). The vertical 0 line represents activation of the PD. Values lower than 0 reflect muscle activation prior to the PD. Values greater than 0 reflect muscle activation after the PD. Because there were no differences between the pre- and postmeasurements, the data were combined showing the LT was activated significantly earlier compared with the UT and MT ($P < .001$). The SA showed significant earlier activation compared with the UT ($P < .001$), MT ($P < .001$), and LT ($P = .046$).

DISCUSSION

The current study investigated the effect of a 6-week exercise program consisting of 4 previously selected exercises in a specific group of overhead athletes with mild impingement symptoms. The initial hypotheses could partially be accepted. The main findings were that the exercise program was able to induce changes in the activation level of the scapular muscles with accompanied improvements in pain and function based on SPADI scores but could not alter the timing of muscle activation during arm elevation in the scapular plane.

Previous studies on the effect of exercise in the treatment of shoulder impingement show statistically and clinically significant effects on pain reduction and improved function but not on increased range of motion or strength. They also found that manual therapy augments the effects of exercise.[36,37] However, when comparing the results of our study with those of others, it must be taken into account that various studies investigated the effect of different exercises, in a different study population, under different training modalities, and with different outcome measures, making it difficult to interpret the results of our study in relation to previous research on this topic. In addition, some authors did not provide much detail regarding their programs for strengthening, other than reporting that muscles of the rotator cuff and scapula stabilizers were involved.[37] Most authors used elastic bands and allowed joint movement for isotonic exercise, whereas others relied on static resistance with isometric contraction. Nevertheless, the current study is similar to the one by Merolla et al,[42] who studied the effect of the 4 selected exercises in a case series of professional volleyball players with scapular dyskinesis. Merolla et al found increased infraspinatus strength after a 6-month training program. They identified decreased pain scores on a visual analog scale from 7.2 ± 1.3 to 2.4 ± 1.8 at 3 months ($P < .01$) and to 2.6 ± 1.4 at 6 months. However, the exercises were combined with SA strengthening and were performed during 6 months, whereas in our study, the athletes performed the 4 selected exercises in isolation during 6 weeks.

The purpose of our study was to evaluate the influence of reeducation of muscle balance and normalization of activation timing by performing only 4 exercises in a specific subgroup of overhead athletes with mild impingement symptoms related to the presence of scapular dyskinesis. The results of the SPADI scores in our study confirm mild symptoms were present in the selected athletes since the values were lower than those in similar studies in which subjects were included on an intention-to-treat basis.[16,31,51] The SPADI values decreased from 29.86 to 11.70 after 6 weeks of training. In the literature, a SPADI score of 8 to 13.2 points is reported as being the minimal clinically important difference.[26,50,60] In our study, this was the case in 23 athletes. In 7 players, full recovery was attained based on a SPADI score of 0 during postmeasurements. The results of this study are very promising since limiting shoulder symptoms in active overhead athletes suffering from persistent mild symptoms might serve as a secondary injury prevention measure, limiting continued low-grade shoulder pain, fear avoidance, and ultimately surgical management requirement.[24]

Concerning the activation levels in the scapular muscles when compared before and after the training program, decreased amounts of trapezius muscle activation, significantly decreased UT/SA, but no changes in the UT/MT and UT/LT ratios were revealed. Consequently, our participants' values were in line with those found in healthy subjects.[58,61] Roy et al[51] already demonstrated significantly decreased EMG activity compared with baseline values immediately after and 24 hours after movement training with feedback in patients with shoulder impingement symptoms. However, this is the first study investigating the effect of the 4 previously selected exercises on the muscle recruitment around the scapula during arm elevation. Previous research provides evidence of reduced activation of the MT, LT, and SA in persons with shoulder pain, combined with an increased UT activation, which is often viewed as a compensatory strategy used by people with painful conditions to elevate their arm. In our study, the UT was the only muscle showing decreased activation levels during each phase of arm elevation when compared before and after the training program. Changes in muscle activation levels after training may be caused by neural adaptations associated with short-term exercise training or may simply be connected with reduced pain levels rather than being a direct result of the training program.[3,5,17] Andersen et al[3] described these phenomena in their "wheel of pain reduction." They propose that pain reduction is a result of training, as increased strength leads to increased maximal muscle activation with lowered relative exposure during low-force tasks such as arm elevation.[3] Indeed, the MVIC values of the 3 trapezius muscle parts were significantly increased in our study, whereas those of the SA were not. Therefore, being able to perform arm elevation with lower relative trapezius muscle activation levels might limit the pathogenetic cascade and might lead to limited impingement symptom development in some athletes.[23] The finding that the UT showed decreased activation levels during each phase of arm movement adds further evidence for this statement since this is the muscle part that is often overactivated in subjects with impingement. However, no changes in the UT/MT and UT/LT ratios were found even though the exercises were selected on the basis of favorable trapezius muscle ratios. This could possibly be caused by already finding rather low ratios during the premeasurements (1.19 for UT/LT) when compared with those with more severe symptoms, as in the study by Smith et al[53] (3.15 for UT/LT).

Concerning muscle onset timing, this is the first study examining the effect of a shoulder training program. In general, early activation of muscles might be a means of increasing muscle stiffness in anticipation of an applied load that would otherwise result in an unwanted change in bony position. The timing of scapular muscle activation has been assessed by several authors, both in healthy and injured overhead athletes. Initially, Wadsworth and Bullock-Saxton[56] showed muscle latency of middle and lower SA to be bilaterally delayed in subjects with impingement and demonstrated that there was an apparently increased variability associated with muscle latencies in subjects with shoulder pain, as indicated by larger within- and between-subject variance. However, Moraes et al[44] did not detect any differences between groups. In addition, the presence of latent trigger points in upward scapular rotators has been found to be of influence.[40] During functional activities such as arm abduction in the scapular plane, Wadsworth and Bullock-Saxton[56] stated that an initial activation of the UT is normal and required for optimal scapula contribution to shoulder complex elevation. Furthermore, Kibler et al[34] demonstrated that the muscle activation at the shoulder during sport-specific movements (eg, serving in tennis) consists of an activation of the UT before the LT in healthy athletes. On the other hand, Wickham et al[59] pointed to an early MT activation during elevation. Although onset timing has been found to be changeable due to therapeutic exercise in the knee and trunk, our results did not reveal any alterations in muscle timing when compared before and after the 6-week exercise program.[13] The statistics only permitted an evaluation of muscle timing when pre- and postmeasurements were combined. Those results reveal the LT was activated significantly earlier than UT and MT, whereas the SA showed significantly earlier activation than the UT, MT, and LT. The results are in line with those found by Glousman et al[25] in injured athletes. However, in the literature, there is no real consensus regarding a normal versus pathological pattern of muscle activation during arm elevation, mainly because of methodological differences between studies, small sample size, and low power.[6,46] In addition, none of the existing studies has prospectively investigated the effect of a shoulder exercise program,[6,46] maybe because the mechanisms for changes in the temporal characteristics of muscle activation are still not definitive.[13] Possibly, timing of muscle activation is the result of a global response, making motor control training more effective than resistance training exercises in altering muscle timing.[13,54] Therefore, the results of this study are to be seen as a first step in evaluating the efficacy of shoulder exercise therapy with the objective to alter the timing of scapular muscle activation. Future research is necessary before any definitive conclusions on this topic can be made.

The strengths of the present study are the specific subgroup of patients, the specific exercise regimen used in isolation, and the good attendance of the participants. In addition, the standardized exercise protocol provides guidance about content, dose, and progression, which enables implementation into everyday practice. However, the results should also be interpreted in light of the methodological limitations of this study. First, the issue of comparing electromyographic data across sessions needs critical discussion. In general, normalization to a MVIC is recommended for diminishing the influence of crosstalk.[32] However, investigating normalized EMG data in a longitudinal design is challenging. Since comparing the absolute level of EMG activity between sessions is inappropriate, normalization is required despite its assumed lack of precision.[28] Nevertheless, drawing conclusions about the modification of EMG patterns should be done in light of the within-session and between-session variability data for each muscle. Within-session variability was very low in our study, with intraclass correlation coefficient (ICC) values ranging from 0.96 to 0.99 for the MVIC tests. The between-session reliability was also calculated with the objective to study the influence of reamplification of surface electrodes on the MVIC values. Therefore, MVICs were determined in a separate group of 25 healthy subjects before and after a 1-week period without intervention. The ICC values were found lower (0.65-0.89) compared with the within-session results, but no statistical differences between both measurements were found, suggesting minimal influence of electrode reamplification ($P < .05$). These results are in line with previous findings of good reproducibility of normalized EMG amplitude reported in the literature.[28] Although interpretation of the absolute muscular effort expressed as a percentage of MVIC may still be affected by the MVIC testing, we believe the within-subject design of this study provides a solid comparison of the relative difference in muscular effort among the pre- and postmeasurements when interpreted in light of its methodological concerns. Second, using a general yes/no method for inclusion of scapular dyskinesis ensures that no conclusions can be made regarding exercise training effects in a specific case, characterized by a particular type of dyskinesis. This rather "simple" method was used in our study because it has been shown to have a high sensitivity and positive predictive value when compared with the results of a 3-dimensional analysis and because further classification into Kibler's 4 types of dyskinesis has been found to show low reliability in a recent study on professional baseball players.[19,55] In addition, Wang and Trudelle-Jackson[57] have shown that there were no significant differences between patients issued customized exercises and those given standard exercises on measures of pain intensity, functional status, shoulder range of motion, and strength, suggesting further individualization in exercise treatment might not be necessary. Nevertheless, overhead athletes with mild impingement symptoms related to the presence of scapular abnormalities can still be considered a very specific group of subjects. Third, the outcome measures were not obtained by a blinded assessor, which is a limitation in this study, as blinded assessment is important to prevent bias and ensure internal validity in a clinical trial. With the objective to minimize such influences, this was managed by blinding each investigator to the pretest results.

The findings from this study also provide a basis for further research. First, randomized controlled trials are necessary to rule out that the natural maturation of the symptoms may have influenced the results. Little is known about natural recovery in patients with subacromial impingement. The use of a control group was done in some studies, demonstrating statistically significant improvement in pain for exercise compared with controls.[37] The results of the current study, a prospective case series, cannot be compared with those of a matched control group, which is a methodological limitation inherent to this type of design. The lack of a control group precludes the study's ability to compare the results of the program with any spontaneous improvement that might occur over a 6-week period. A randomized clinical trial is generally the preferred study design, but the external validity can be compromised by the ability to recruit a representative sample. In addition, a recent study emphasized that the influences from this research method on clinical decision making can still be limited.[39] Second, future studies could simultaneously investigate the effect on the 3-dimensional movement pattern of the scapula in combination with the electromyographic analysis or evaluate the effect on additional parameters, such as the strength of the scapular muscles, by using handheld or isokinetic dynamometer testing. Third, it could be of interest to focus on follow-up studies investigating secondary injury risk and cost-effectiveness of a home exercise program compared with other treatment modalities. Further research is also needed to evaluate the efficacy of other physical therapy protocols for shoulder impingement symptoms and to assess comprehensive treatment that is tailored to individual patients, as occurs in clinical practice.

In conclusion, this is the first longitudinal study investigating the effect of 4 previously selected exercises for rehabilitation of scapular muscle performance in overhead athletes with mild impingement symptoms. The results indicate that a 6-week scapular exercise program improves pain and function based on SPADI scores, reduces relative trapezius muscle activation, and alters UT/SA ratios, but it does not change the timing of the scapular muscles during arm elevation in the scapular plane. Studies evaluating the efficacy of exercise treatment in overhead athletes who experience pain but are not yet enrolled in a physical therapy program are scarce. The current study evaluating an exercise program based on previously selected exercises adds valuable knowledge for managing patients with mild impingement symptoms. Future research is necessary to confirm or refute our findings.

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