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Experimental Study

Comparison of muscular activities between subjects with and without scapular downward rotation impairment during diagonal pattern of exercises

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A R T I C L E I N F O

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A B S T R A C T

Backgrounds: One form of abnormal scapular alignment is scapular downward rotation (SDR). Changes in muscle function in SDR have not been clearly identified, and SDR exercises also require investigation. Although a diagonal pattern of exercise is commonly used as part of the exercise protocol, a direct comparison of shoulder and scapular diagonal exercises has not yet been conducted. The objectives of this study were to determine the altered activation of the scapular musculature in the SDR group and to investigate which diagonal pattern of exercise effectively activates the scapular musculature.
Methods: Thirty-two participants (18 in the control group and 14 in the SDR group) volunteered to participate in this study. Electromyographic signals were collected from four muscles, the upper trapezius (UT), lower trapezius (LT), serratus anterior (SA), and anterior deltoid (AD), during standing performance of diagonal shoulder and scapular exercises.
Results: The control group showed significantly lower UT activity, UT/LT ratio, and UT/SA values than the SDR group ($p < .05$). Activation of the AD was significantly higher in the SDR than in the control group ($p < .05$). SA and AD activation were significantly higher in shoulder diagonal pattern exercises than in scapular diagonal pattern exercises ($p < .05$). The scapular posterior elevation pattern exercise showed significantly higher UT and LT activities than anterior elevation and shoulder diagonal pattern exercises ($p < .05$).
Conclusion: Our findings suggest that reduced activation of the UT could lead to greater activation in the AD in SDR. Scapular posterior elevation exercise is advantageous as selectively activates the trapezius musculature, and shoulder diagonal pattern exercise is advantageous in activating the SA and AD.

1. Introduction

Optimal alignment and movement of the scapulae is known to play an important role in normal glenohumeral movement (Lin et al., 2010; Reinold et al., 2009; Neumann, 2002). Some previous reports have suggested that dysfunction of scapular musculature could lead to abnormal scapular alignment and upper extremity dysfunction (Borstad et al., 2009; Tsai et al., 2003). Therefore, impaired scapular alignment and dysfunction of the scapular musculature could be considered risk factors for upper extremity dysfunction (Page et al., 2010). One form of abnormal scapular alignment is scapular downward rotation (SDR), which includes depression, abduction, and tilt of the scapula. SDR is characterised by increased upper trapezius (UT) muscle length and levator scapular stiffness, and potentially generates insufficient upward rotation of the scapula (Lee et al., 2016). Ha et al. (2011) indicated that patients with SDR tend to show decreased cervical range of motion and increased vertical stress on the cervical vertebrae due to increased length-related tension of the upper trapezius.

Previous studies proposed that assessments for SDR include passive correction with braces and exercise programs (Ha et al., 2011, 2016; Lee et al., 2016; Kang et al., 2015). A shoulder-lifting apparatus has been used to decrease upper trapezius muscle tension (Ha et al., 2011), and crossed brassiere straps have been used to normalise muscular activation and reduce pain (Kang et al., 2015).

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In addition to passive correction, exercise programs have been proposed and have shown positive effects. A 6-week program entailing non-restive and resistive upper extremity exercises was beneficial for restoring scapular alignment and increasing the power of the scapular upward rotators (Ha et al., 2016). Lee et al. (2016) also reported that variations in the shrug exercise were effective for enhancing the upward rotation angle and muscular activity. Although methods of passive correction and exercise programs have positive effects for regaining muscular function, further exercise programs need to be investigated.

Classical proprioceptive neuromuscular facilitation interventions suggest two spiral-diagonal elevation patterns associated with scapular and shoulder patterns. With respect to shoulder patterns, have focused, respectively, on flexion, adduction, and external rotation and on flexion, abduction, and external rotation. For scapular patterns, exercises have highlighted scapular anterior elevation (AE) and posterior elevation (PE) (Adler et al., 2008). Recent studies have explored scapular muscle activity during diagonal exercise patterns. A previous study reported that selective activation of the scapulothoracic musculature could be accomplished by employing a diagonal exercise pattern (Witt et al., 2011). Ekstrom et al. (2003) suggested that a flexion–adduction–external rotation pattern of arm elevation was effective for activating scapulothoracic muscle activity. These studies investigated the shoulder diagonal pattern of exercises; however, information on muscle activity in the scapular diagonal pattern of exercise is still lacking. Therefore, there is a need to compare scapula-related muscle activities during scapular and shoulder diagonal exercise patterns and determined which muscles are activated during each exercise.

Previous electromyography studies of related exercises for scapular dysfunction have investigated only the scapulothoracic musculature (Lee et al., 2016; Park and Yoo, 2015). Studies that compared muscle activity between groups with and without scapular dysfunction found no clear differences due to limited exercise programs (Park and Yoo., 2015). Although SDR is a form of scapular dysfunction, limited investigation of muscle and exercise programs makes it difficult to determine whether SDR could generate functional musculoskeletal problems and whether exercise programs are effective for reducing SDR. Therefore, in the present study, we examined the activation of scapular and shoulder musculature in symptomatic SDR patients and an asymptomatic group during shoulder and scapular diagonal pattern exercises.

2. Methods

2.1. Subjects

Subjects were recruited at a local university. To identify subjects with SDR, we used the following screening criteria: (1) the scapulae were downwardly rotated; the inferior angle appeared closer to the spine than the root of the spine of scapulae by visual appraisal (the inferior angle moved medially and the glenoid fossa rotated to face caudally) (Caldwell et al., 2007); (2) the clavicle appeared to be horizontal or the acromioclavicular joint was lower than the sternoclavicular joint by visual appraisal (Ha et al., 2016); (3) the medial borders of the scapulae were less than 3 inches from the spine (measured from the midpoint of the vertebral border of the scapula to the corresponding thoracic spinous process using a tape measure) (Caldwell et al., 2007); (4) the visual analogue score at rest was less than 3 (mild pain). The final test in the present study was performed using 32 amateur athletes (18 in the asymptomatic group and 14 in the SDR group); their demographic data are presented in Table 1 (see Table 1). Subjects were excluded if they were (1) unable to perform at least 160° of shoulder abduction, (2) showed a positive sign in the Hawkins and Neer impingement tests. In addition, subjects with a history of traumatic injuries within 8 weeks that could affect upper extremity function were also excluded. All classifying procedures were performed by physiotherapists with 10 years of experience. Informed consent was obtained from all subjects before beginning the study, as required by the Kaya University Faculty of Health Science Human Ethics Committee (IRB No. 20160140).

2.2. Instruments

Surface electromyography (sEMG) data were collected using a wireless EMG system (Free EMG300, BTS Bioengineering, Italy). The sEMG signals were sampled at a frequency of 1000 Hz. The data obtained were computerised using EMG acquisition software (BTS). Four surface electrodes were attached parallel to the muscle fibres on the dominant right side (1) on the upper trapezius (UT) muscle, at approximately half the distance between the seventh cervical spinal process and the acromion, (2) on the lower trapezius (LT) muscle at 1.5 cm lateral and oblique to the T6 spinal process, (3) on the serratus anterior (SA) muscle at the mid-axillary line over the seventh rib, and (4) on the anterior deltoid (AD) muscle at the anterior aspect of the arm approximately 4 cm below the clavicle (Cram et al., 1998). Before attaching the electrodes, the skin was shaved, abraded with fine sandpaper, and cleaned with alcohol.

2.3. Procedure

The MVC of each muscle was measured following procedures from a previous study (Kendall et al., 2005) to enable normalisation of the EMG amplitude. The mean value of two trials for each muscle activity was taken as the maximum voluntary isomeric contraction (MVC). A 3-min rest was provided between trials. Participants performed two diagonal shoulder exercises: flexion–adduction–external rotation (D1F) and flexion–abduction–external rotation (D2F), and two diagonal scapular exercises: anterior elevation (AE), and posterior elevation (PE) in the standing position. To perform shoulder D1F, the participant started with the right arm down by the right side and brought it up towards the left ear, moving through the glenohumeral actions of flexion, adduction, and external rotation (see Fig. 1A). To perform shoulder D2F, the participant started with the arm at the left side of the waist and brought the arm up above the right side of the head, which involved the glenohumeral movements of flexion, abduction, and external rotation (see Fig. 1B). To perform scapular AE, the participant started with the right arm down by the right side and brought the right scapula up towards the tip of nose (see Fig. 2A). To perform scapular PE, the participant brought the right scapula up towards the posterior region of the ear (Adler et al., 2008) (see Fig. 2B).

We applied 10% of the subject's weight as a cuff load for arm elevation during the diagonal exercise, by placing a weight bag on the subject's upper arm. Each subject conducted exercises within a period of 3 s, timed using a metronome. Subjects were given a 3-min practice period to acclimatise to the required movement and speed. A 3-min rest was provided between exercises, and a 60-s

Table 1
Averaged subject's demographic data.

	Asymptomatic group	SDR group
Age(year)	22.33 ± 1.37	23.21 ± 2.15
Height(cm)	175.72 ± 4.40	175.07 ± 8.30
Weight(kg)	72.61 ± 5.41	71.57 ± 5.40

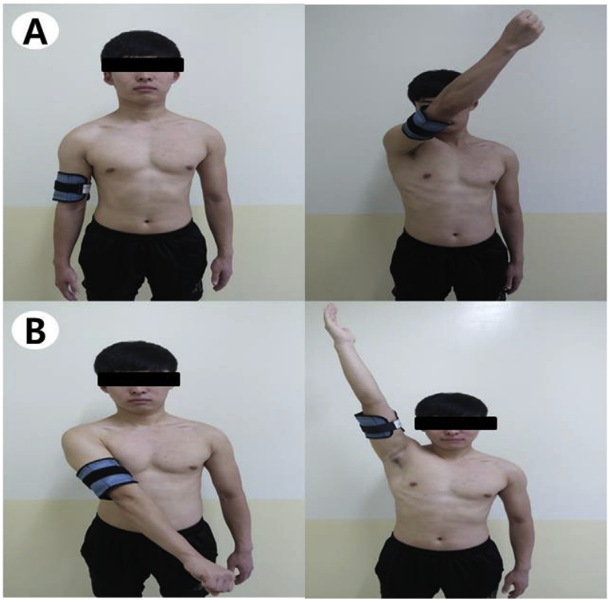

Fig. 1. Two diagonal shoulder exercises: A) D1F, B) D2F.

rest was provided between trials. All raw sEMG data were root mean squared and smoothed with a 250-ms moving window using analysis software. The sEMG values of the three trials were averaged and normalised against the MVC values of the UT, LT, SA, and AD for statistical analyses. To identify the relative activity of the muscles, the ratios between UT and LT (UT/LT) and between UT and SA (UT/SA) were calculated and used for statistical analyses.

2.4. Statistical analysis

PASW Statistics (ver. 18.0; SPSS, Chicago, IL, USA) was used to analyse differences in the %MVC of each muscle, and in the ratios between muscles. A two-way repeated-measures analysis of variance (ANOVA) was used to determine the effects of group differences and exercise on the EMG data. Specific pair-wise comparisons between exercise variants were made using the Bonferroni correction. Statistical significance was set at $p < .05$.

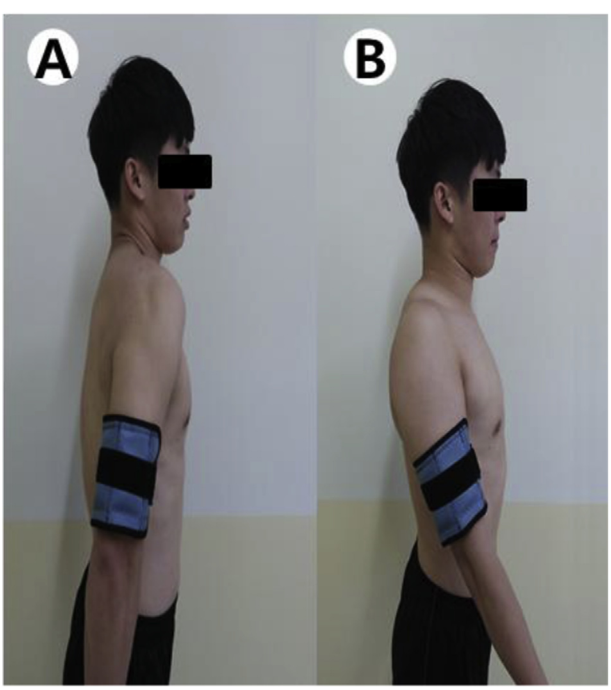

Fig. 2. Two diagonal scapular exercises: A) anterior-elevation, B) posterior-elevation.

3. Results

3.1. Group comparisons

Group differences were found in the %MVCs of the UT, AD, UT/LT ratio, and UT/SA ratio. The control group exhibited significantly greater UT, UT/LT ratio, and UT/SA ratio compared with the SDR group ($p < .05$). In contrast, the %MVCs of the AD were significantly higher in the SDR group than in the control ($p < .05$; see Table 2, Fig. 3).

3.2. Exercise comparisons

The average %MVC values of the UT in the AE were significantly lower than in other exercises (see Fig. 3, $p < .05$). For the LT, the PE and D2F showed significantly higher %MVC values than the AE and D1F (see Fig. 3, $p < .05$). The normalised EMG data of the SA were significantly higher in shoulder diagonal pattern exercises than in scapular diagonal pattern exercises (see Fig. 3, $p < .05$). A significant correlation effect was found between the exercise and group factors in the AD ($p < .05$). Further analysis of each group by a one-way repeated ANOVA revealed significantly more AD activation in the shoulder diagonal pattern exercises than in the scapular diagonal pattern exercises ($p < .05$).

The ratio between UT and LT activation (UT/LT) was significantly higher in the D1F exercise than observed in the AE and D2F (see Fig. 4, $p < .05$). The scapular PE pattern exercise showed significantly higher UT/SA ratio values than the AE in shoulder diagonal pattern exercises (see Fig. 4, $p < .05$).

4. Discussion

We investigated scapular and shoulder musculature activity in subjects with and without SDR during diagonal pattern upper extremity exercises. For the UT and AD muscle activities, significant group differences were observed; however, the results were contradictory. The group with SDR showed significantly lower UT activity and significantly higher AD activity than the control group. Because SDR is characterised by increased upper trapezius muscle length, decreased upper trapezius activity is a natural result, as shown in previous studies (Lee et al., 2016; Kang et al., 2015). Interestingly, the current study also demonstrated increased anterior deltoid activity in the SDR group. Changes in scapular alignment and movement have been associated with shoulder dysfunction (Huang et al., 2016; Kibler et al., 2002). Previous clinical literature has suggested that decreased upward rotation in SDR can lead to subacromial impingement during arm elevation (Page et al., 2010). Increased deltoid activity and relatively decreased rotator cuff muscle activity have been observed in patients with shoulder disorders (Phadke et al., 2009). Although mild SDR may not be directly related to functional limitations, repetitive arm elevation movement with increased anterior deltoid activity and reduced scapular upward rotation could move the humeral head and acromial arch closer together.

Subsequent analysis identified significant group differences in both the UT/LT and UT/SA activation ratios. Generally, ratio values are considered criteria for assessing balanced activation of the scapulothoracic muscles (De Mey et al., 2012; Schory et al., 2016). Previous studies that investigated ratio values in patients with

Table 2
The average and standard deviation (SD) of %MVIC values during exercises.

Muscles	Group	Exercise - %MVIC (Mean ± SD)			
		AE	PE	Flex-add-ext	Flex-abd-ext
Upper trapzeius (UT)	Control	20.04 ± 15.67	39.44 ± 15.88	35.09 ± 17.47	33.24 ± 11.39
	SDR	9.51 ± 6.85	26.76 ± 12.92	18.98 ± 6.06	22.93 ± 9.26
Lower trapezius (LT)	Control	16.31 ± 12.11	25.53 ± 14.71	10.94 ± 5.84	28.50 ± 14.68
	SDR	13.09 ± 7.51	30.11 ± 19.10	12.80 ± 7.01	35.25 ± 18.62
Serratus anterior (SA)	Control	14.57 ± 3.31	13.22 ± 8.25	49.26 ± 26.25	48.28 ± 23.16
	SDR	21.63 ± 8.08	16.03 ± 8.42	39.26 ± 19.94	38.59 ± 19.56
Anterior deltoid (AD)	Control	5.31 ± 3.11	6.85 ± 3.88	30.16 ± 9.72	36.64 ± 10.98
	SDR	4.00 ± 1.67	6.10 ± 3.89	46.31 ± 11.50	52.31 ± 5.89
Ratio UT/LT	Control	1.83 ± 1.63	2.49 ± 2.34	3.95 ± 2.42	1.41 ± 0.67
	SDR[a]	0.88 ± 0.62	1.22 ± 0.95	1.86 ± 0.92	0.80 ± 0.40
Ratio UT/SA	Control	1.58 ± 1.65	3.96 ± 2.63	0.84 ± 0.43	0.82 ± 0.42
	SDR[a]	0.49 ± 0.41	1.87 ± 0.90	0.58 ± 0.28	0.67 ± 0.30

[a] Significant difference between conditions.

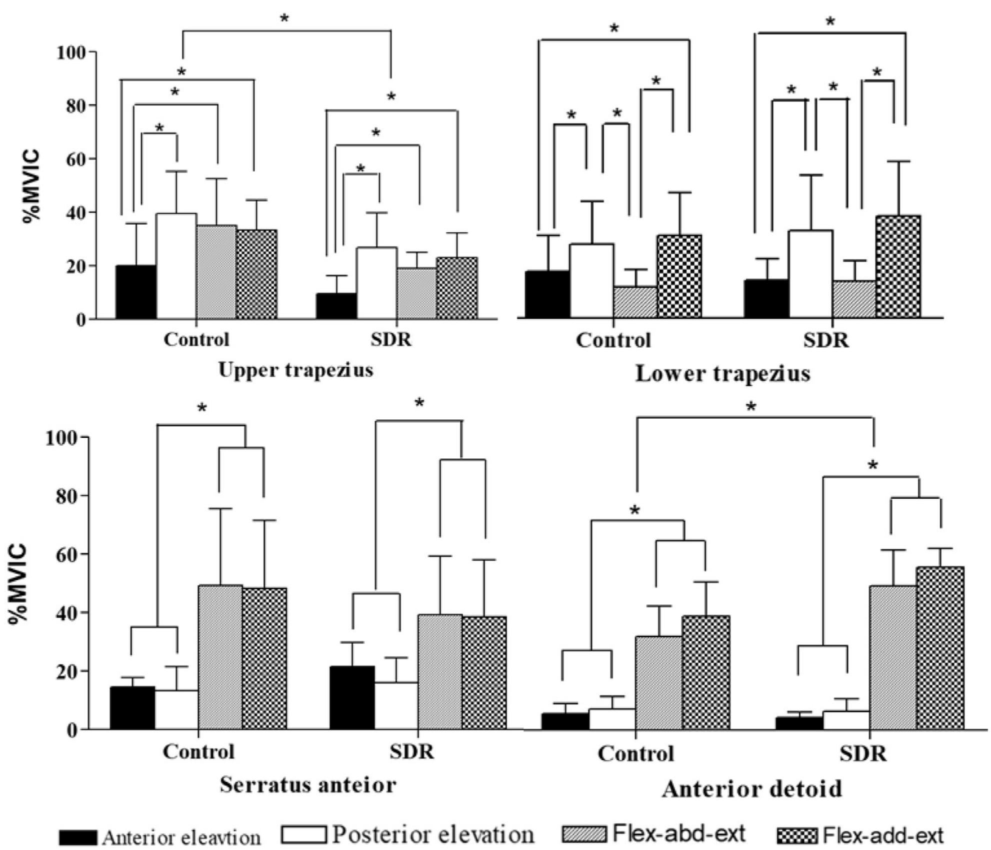

Fig. 3. The normalised EMG data of the upper and lower trapezius, serratus anterior, and anterior deltoid in exercise variation.
*Significant difference between conditions.

shoulder impingement syndrome and scapular dyskinesis suggested greater UT/LT and UT/SA activation ratios (Michener et al., 2016; De Mey et al., 2012; Lin et al., 2010). Conversely, ratio values obtained in the current study were lower in the SDR group than in the asymptomatic group. Unlike the case in scapular dyskinesis and shoulder impingement, attenuated UT activity relative to that of other scapulothoracic musculature contributes to depression of the scapulae (Ha et al., 2016; Lee et al., 2016). Previous studies investigated UT/LT and UT/SA ratios in asymptomatic groups and obtained ratio values of 1.5–3.5 (Larsen et al., 2013; Schory et al., 2016), which were greater than the ratio values observed in the SDR group in the present study.

We also examined the four diagonal patterns of the exercises. When comparing scapular pattern exercises with shoulder diagonal pattern exercises, the activities of the AD and SA showed greater % MVIC in the shoulder diagonal exercises than in the scapular diagonal exercises. In a recent systemic review that explored scapular muscle activation in various shoulder exercises, the diagonal pattern of exercise was advantageous in generating relatively greater activation of the SA (Schory et al., 2016). Both shoulder diagonal pattern exercises have components of glenohumeral flexion and external rotation when shoulder movement requires SA and AD muscle activity (Lin et al., 2010; Reinold et al., 2009). With respect to the selective activation of SA and AD, shoulder diagonal pattern exercise

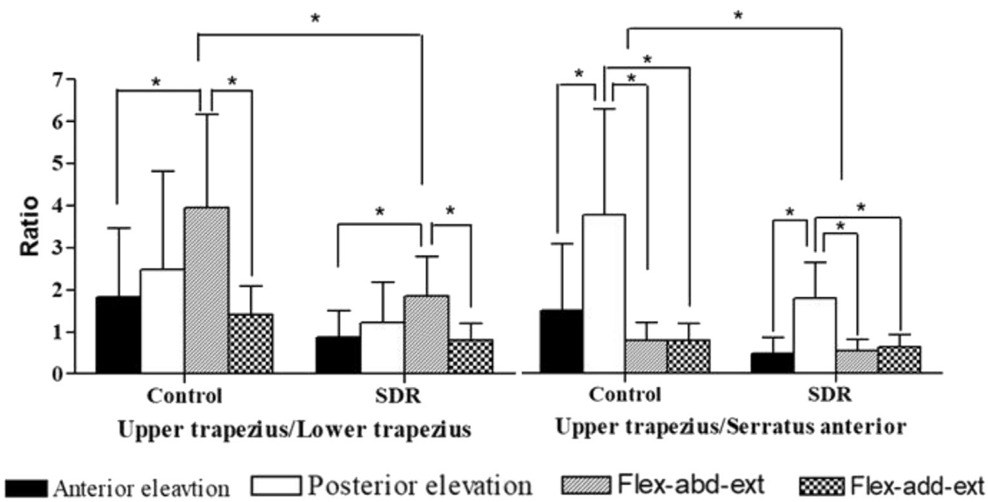

Fig. 4. The ratio between upper trapezius and lower trapezius (UT/LT), and between upper trapezius and serratus anterior (UT/SA).
*Significant difference between conditions.

was a better option than scapular diagonal exercises.

Both AE and PE exercises could be categorised as shrug exercises. In other words, AE is characterised as a shrug emphasising scapular anterior tilt, and PE as a shrug emphasising scapular posterior tilt. In a comparison of both scapular pattern exercises, the activities of the UT and LT differed significantly depending on the exercise; both muscles showed higher %MVIC in the PE than in the AE pattern. The UT is attached from the posterior neck region to the scapulae, so the direction of pull is in the posterior and superior directions (Muscolino, 2011). Therefore, the line of pull in the UT muscle was adequate under the PE pattern to optimise activation of the muscle. Similarly, a previous study also reported that shrug exercises in the frontal plane were more effective in activating UT activity than was exercise in the scaption plane (Lee et al., 2016). With respect to LT activation, our results suggest that the PE and D2F exercises are more advantageous for activating the LT than the AE. Both PE and D2F exercises include the components of scapular external rotation and adduction (Adler et al., 2008), which induce concentric contraction of the LT.

Some limitations to the present study must considered. First, no scientific studies have suggested specific classification and criteria for SDR, so further study is necessary to demonstrate classification criteria for SDR. Second, the present study could not record kinematic data, and the accuracy of diagonal elevation could not be measured. Finally, the present study could not measure the activation of rotator cuff muscles. Measuring rotator cuff muscle activity in the SDR group would clearly demonstrate the musculoskeletal mechanisms of these exercises.

5. Conclusion

There were three main findings in the present study. There were differences in scapulothoracic muscle activity between the groups with and without SDR, indicating that reduced activation of the UT can induce greater activation of the AD in SDR patients. Second, scapular posterior elevation exercise is advantageous for selectively activating the trapezius musculature. Finally, shoulder diagonal pattern exercise is advantageous for activating the SA and AD.

Conflicts of interest

The authors declare no conflict of interest.

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