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Scapula-Focused Exercises With or Without Biofeedback and Corticospinal Excitability in Recreational Overhead Athletes With Shoulder Impingement

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Context: Individuals with shoulder impingement syndrome (SIS) exhibit changes in corticospinal excitability, scapular kinematics, and scapular muscle-activation patterns. To restore the scapular kinematics and muscle-activation patterns in individuals with SIS, treatment protocols usually include scapula-focused exercises, such as scapular-orientation and strength training.

Objective: To investigate whether scapular-orientation and strength training can reverse the altered corticospinal excitability of recreational overhead athletes with SIS.

Design: Randomized controlled clinical trial.

Setting: University laboratory.

Patients or Other Participants: Forty-one recreational overhead athletes with SIS: 20 in the scapular-orientation group (age = 26.45 ± 4.13 years, height = 171.85 ± 7.88 cm, mass = 66.70 ± 10.68 kg) and 21 in the strengthening group (age = 26.43 ± 5.55 years, height = 171.62 ± 5.87 cm, mass = 68.67 ± 10.18 kg).

Intervention(s): Both groups performed a 30-minute training protocol consisting of 3 exercises to strengthen the lower trapezius (LT) and serratus anterior muscles without overactivating the upper trapezius muscles. Participants in the scapular-orientation group were instructed to consciously activate their scapular muscles with electromyographic biofeedback and cues, whereas the strengthening group did not receive biofeedback or cues for scapular motion.

Main Outcome Measure(s): Corticospinal excitability was assessed using transcranial magnetic stimulation. Scapular kinematics and muscle activation during arm elevation were also measured.

Results: After training, both groups demonstrated an increase in motor-evoked potentials in the LT ($P = .004$) and increases in scapular upward rotation ($P = .03$), LT activation ($P < .001$), and serratus anterior activation ($P < .001$) during arm elevation. Moreover, the scapular-orientation group showed higher LT activation levels during arm elevation after training than the strengthening group ($P = .03$).

Conclusions: With or without biofeedback and cues, scapula-focused exercises improved scapular control and increased corticospinal excitability. Adding biofeedback and cues for scapular control during exercise helped facilitate greater LT activation, so feedback and cues are recommended during scapula-focused training.

Key Words: transcranial magnetic stimulation, scapular dyskinesis, scapular-orientation exercise, strength training

Key Points

- Scapula-focused exercises improved scapular control and potentially reversed the central alterations of individuals with shoulder impingement syndrome.
- Although scapula-focused training both with and without biofeedback had positive effects on scapular control, biofeedback and cues are recommended during training to further increase lower trapezius activation during arm movement.

Shoulder impingement syndrome (SIS) is the most common shoulder problem among athletes involved in overhead sports.[1] One important factor contributing to SIS is altered scapular kinematics.[2] Decreased scapular posterior tilt and upward rotation and increased internal rotation have been observed in patients with SIS. These kinematic alterations may reduce the subacromial space and lead to the impingement of subacromial tissue.[3] Patients with SIS also have an overactive upper trapezius (UT) and decreased activation of the lower trapezius (LT) and serratus anterior (SA),[4] resulting in an increased muscle-activation ratio of UT:LT and UT:SA during shoulder movement.[5]

Scapula-focused exercises are usually prescribed for patients with SIS to restore scapular kinematics and muscle-activation patterns. These exercises include scapular-orientation and strength training.[5–9] Scapular-strength training typically involves exercises that cause a high level of activity in the LT and SA muscles and low level of activity in the UT muscle.[5,8] Scapular-orientation training includes feedback, including visual, auditory, tactile, or electromyographic cues, to aid directly in the control of the scapula during strength training or functional shoulder movement.[6,7,9] Both scapular-orientation and strength training have been demonstrated to improve scapular kinematics and muscle recruitment.[6–9] Although researchers have reported that providing extra feedback during strength training could further improve scapular kinematics and muscle activation,[6] no investigators have directly compared the effects of scapular-orientation and strength training in patients with SIS.

In addition to the alterations in scapular kinematics and muscle activation, researchers have reported central changes in individuals with SIS.[10,11] Investigators who used transcranial magnetic stimulation (TMS) reported decreased corticospinal excitability and increased cortical inhibition of the shoulder muscles in these individuals.[10,11] The central changes are thought to be related to deficits in neuromuscular control.[12] The low efficacy of treatments and persistence of symptoms may be associated with these changes in the central nervous system.[10,12]

Identifying exercises that can reverse these central changes in individuals with shoulder problems is crucial. Motor-skill and strength training induce different corticomotor adaptations related to the distal muscles of heathy participants.[13,14] Although motor-skill training has been demonstrated to increase corticospinal excitability and decrease cortical inhibition, strength training may only decrease cortical inhibition but has not been associated with changes in corticospinal excitability.[13–15] Therefore, to maximize the treatment effects on cortical reorganization, researchers have recommended including motor-skill training in protocols for individuals with musculoskeletal problems.[16] Motor-skill training is usually conducted by providing targets, cues, or feedback, and this paradigm is like scapular-orientation exercise for patients with shoulder problems. Therefore, scapular-orientation exercises may have greater effects on excitability than scapular muscle strength training. However, to our knowledge, no one has investigated whether these 2 scapula-focused exercise regimes change the corticospinal excitability of individuals with SIS. Therefore, we examined the changes in the corticospinal mechanisms after a 30-minute session of scapular-orientation or strength training in individuals with SIS. We hypothesized that after scapular-orientation or strength training, cortical inhibition would decrease and that only scapular-orientation training would increase corticospinal excitability.

METHODS

Study Design

This was a randomized controlled clinical trial (ClinicalTrials.gov Identifier NCT04014491) to compare the effects of a single session of scapular-orientation and strength training. The participants drew lots after the pretest to be randomly assigned to the scapula-orientation–training (scapular-orientation) group or the strength-training (strengthening) group. The participants provided demographic information and responses to questions related to symptoms. Shoulder function was determined using the Flexi Level Scale of Shoulder Function Chinese Version (FLEX-SF) questionnaire. A lower FLEX-SF score indicates a lower level of shoulder function (total score = 48). Outcomes included corticospinal excitability, scapular kinematics, and scapular muscle activation, which were tested before and after the 30-minute exercise training. The first author (S.L.L.) collected outcome measures and provided the 30-minute training.

Table. Participant Characteristics

Characteristic	Training Group: Scapular Orientation (n = 20)	Training Group: Strengthening (n = 21)	*P* Value[a]
	No.		
Sex, male/female	18/2	17/4	.41
Dominant hand, right/left	19/1	18/3	.32
Affected side, right/left	19/1	18/3	.32
	Mean ± SD		
Age, y	26.45 ± 4.13	26.43 ± 5.55	.99
Height, cm	171.85 ± 7.88	171.62 ± 5.87	.92
Mass, kg	66.70 ± 10.68	68.67 ± 10.18	.55
Duration of symptoms, mo	20.10 ± 22.33	18.14 ± 22.78	.78
Pain on the testing day[b]	2.70 ± 1.62	2.67 ± 2.00	.95
Pain during sport activity[b]	5.07 ± 1.33	5.67 ± 1.39	.24
Flexilevel Shoulder Function Scale score	39.15 ± 6.89	38.23 ± 6.30	.66

[a] Chi-square test was used to analyze data of sex, affected side, and dominant hand; independent *t* test was used to analyze other variables.

[b] Measured using a numerical rating scale.

Aiming to test within-day intrarater reliability of all measures, we conducted 2 other studies. Before the main experiment started, one pilot study was conducted to determine the reliability of the scapular muscle activation and kinematics with 19 healthy participants (6 women, 13 men; age = 24.8 ± 2.1 years, height = 171.4 ± 7.9 cm, mass = 67.6 ± 12.8 kg). Kinematics and muscle activation were measured in 2 sessions separated by a 30-minute interval. We also recruited 30 participants with SIS from the main experiment to test the reliability of the TMS variables at another visit (4 women, 26 men; age = 26.9 ± 5.1 years, height = 170.9 ± 7.1 cm, mass = 66.8 ± 10.3 kg, pain on the testing day = 2.0 ± 1.3 on a numeric rating scale [0 = *no pain*, 10 = *worst pain*]). The TMS measures were also collected in 2 sessions separated by a 30-minute interval. The intraclass correlation coefficient (ICC) model 3 (2-way mixed effects with a consistency definition) was used to calculate the reliability of the rater (S.L.L.) for all measures.

Participants

A total of 45 individuals were recruited from universities and communities in Taipei, and 41 individuals were enrolled in this study (Table). We sought to enroll participants with scapula-control problems but without tendon degeneration. Because tendon degeneration usually occurs after 40 years of age, we only enrolled recreational overhead athletes who were aged 20–40 years, had type I or II scapular dyskinesis, and had a positive result in the scapula-assist test.[2,17] These athletes were included if they engaged in overhead sports for >4 h/wk; had shoulder pain localized at the anterior or lateral aspect of the shoulder for >2 weeks; and had SIS, confirmed via at least 3 of the following: (1) positive Neer test, (2) positive Hawkins sign, (3) positive empty can test, (4) positive resisted external rotation test, (5) painful arc during arm elevation, and (6) tenderness of the rotator cuff tendons.[7]

Individuals were excluded if they had the following: (1) a history of dislocation, fracture, or surgery of the upper extremity or neck; (2) a history of direct contact injuries to the neck or upper extremities within the 12 months before the study; (3) a concussion within the 12 months before the study or a history of ≥3 concussions; (4) brain injury and neurological impairment; or (5) contraindications to the use of TMS, such as having a history of seizure or metal implants or taking antidepressant medication.[7,18] All participants provided written informed consent, and the study was approved by the Institutional Review Board of National Yang-Ming University (YM108043F).

Instrumentation

Scapular Muscle Activation and Kinematics During Arm Elevation. When participants performed the testing task of arm elevation on their affected side, they were comfortably seated on a chair with a 2-kg dumbbell held in their hand. They were instructed to perform 5 trials of arm elevation in the scapular plane (30° anterior to the frontal plane) with 5-second raising and 5-second lowering phases. The scapular muscle activation and kinematics during arm elevation were measured simultaneously and synchronized by an external trigger.

Surface electromyography of the UT, LT, and SA during arm elevation was recorded using an 8-channel FM/FM Telemetric electromyography (EMG) system (TeleMyo 2400T G2; Noraxon) with a sampling rate of 1500 Hz. We placed Ag/AgCl hydrogel surface electrodes (Kendall ECG electrodes; Covidien) with an interelectrode distance of 20 mm on the muscles based on previous studies.[19,20] This system provided an input impedance of 10 MΩ, common-mode rejection ratio of 85 dB, and gain of 2000. The data were recorded using MyoResearch (MyoResearch XP Master Edition; Noraxon) software. The ICCs of the UT, LT, and SA EMG during arm elevation were 0.946–0.975, 0.721–0.952, and 0.858–0.976, respectively.

Three-dimensional humerothoracic and scapulothoracic (scapular) kinematics during arm elevation were measured using an electromagnetic tracking system (Liberty; Polhemus) with sensors attached to the thorax (the spinous process of the third thoracic spine), scapula (posterior surface of the acromion), and arm (distal third of the humerus).[21] Motion analysis software (The MotionMonitor; Innovative Sport Training) was used for data collection with a sampling rate of 120 Hz. The anatomic coordinate systems of the scapula, humerus, and thorax were established based on the recommendation of the International Society of Biomechanics.[22] All bony landmarks for the anatomic coordinate systems were digitized using a stylus, except that the *center of the humeral head* was defined as the point that moved the least during a small arc of shoulder motion and calculated using a least-squares algorithm.[22,23] The ICCs of scapular upward rotation, posterior tilt, and internal rotation during arm elevation were 0.817–0.923, 0.740–0.981, and 0.677–0.867, respectively.

The TMS Variables. The TMS variables were tested using TMS (Magstim 200^2; Magstim) with a 70-mm figure-of-8 stimulation coil. The LT was selected as the target muscle based on a study in which researchers reported alterations of both corticospinal excitability and cortical inhibition of the LT in individuals with SIS.[11] When stimuli were applied to the hotspot of the LT, the motor-evoked potentials (MEPs) of the SA were also collected. The *hotspot* was defined as the site where the lowest TMS intensity was required to trigger MEPs >100 µV in 5 of 10 trials. This *lowest TMS intensity* was defined as the active motor threshold (AMT) of the LT.[24]

Electromyographic signals of the LT and SA were collected using LabChart 8 (LabChart8; ADInstruments) software and surface EMG (ML4846 PowerLab 4/26; AD Instruments) and an amplifier (Dual Bio Amp; ADInstruments) with an input impedance of 1 MΩ, common-mode rejection ratio of 105 dB, gain of 500, and sampling rate of 4000 Hz. Five-minute maximal voluntary isometric contractions (MVICs) of the LT and SA were assessed using muscle contractions of horizontal abduction at 120° of shoulder abduction in prone and shoulder protraction against a wall at 120° of arm elevation, respectively.[25,26] When the TMS variables were measured using a single-pulse paradigm, the participants wore a swimming cap, sat on a chair, and held their shoulder at 90° of elevation in the scapular plane. Participants maintained the activation of the LT between 20% and 25% of MVIC with a monitor displaying the target contraction levels and real-time muscle contraction. The coil was moved around to search for the hotspot of the LT with the handle pointing in a posterolateral direction at a 45° angle. When MEPs of the LT at 120% of AMT were tested for 20 trials, MEPs of the SA were simultaneously collected. Both AMT and MEPs at 120% of AMT presented corticospinal excitability. The cortical silent period (CSP), a measure of cortical inhibition, was collected at 150% of AMT for 20 trials.[11] When the TMS variables were measured in the posttest, the stimulus intensities at the percentage of the maximum stimulator output (MSO) for MEP and CSP were the same as those used in the pretest, but the AMT was determined again at the posttest. The ICCs of the TMS variables ranged from 0.911 to 0.981.

Protocol

Exercise Training Protocol. Both groups performed the same exercise program with a dumbbell. The program consisted of (1) arm elevation in the scapular plane to 90° in a sitting position (Figure 1A), (2) shoulder flexion to 90° in a side-lying position (Figure 1B), and (3) shoulder external rotation in a side-lying position (Figure 1C). Exercises (2) and (3) are the movements that facilitate high activation of the LT and SA with low ratios of UT:LT and UT:SA.[6] Participants performed each exercise without pain for 3-second concentric and 3-second eccentric phases, standardized using a metronome. Three 10-repetition sets of each exercise were performed. If participants reported pain during the process of setting training intensity or the training, the weight was decreased until they perceived no pain during the movement. A licensed physical therapist with 2 years of practice experience (S.L.L.) provided the training for both groups.

Scapular-Orientation Training. Scapular-orientation training aimed to restore better scapular control via providing feedback and cues. The weight of the dumbbell used during training was chosen according to body weight (3 kg for 50–59 kg, 4 kg for 60–69 kg, and 5 kg for 70–85 kg)[6] then adjusted to a training intensity of 3 or 4 (*moderate* or *somewhat hard*, respectively) on the Modified Rating of Perceived Exertion (modified RPE) scale.[27] The weight was provided to facilitate scapular control. Muscle activation of the UT and LT was recorded during the training, with the real-time ratio of UT:LT displayed on a monitor. First, participants were instructed to perform each training exercise 3 times without any cues to determine the baseline muscle-activation ratio of

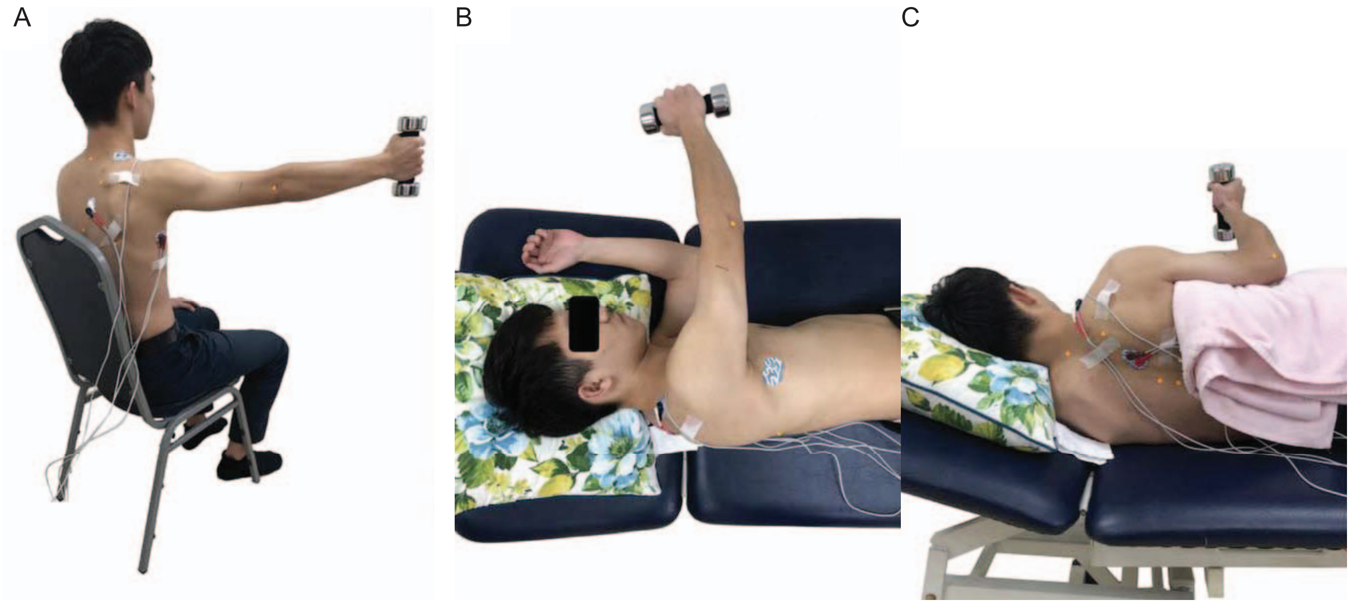

Figure 1. Exercise program for both scapular-orientation and strengthening groups consisted of, A, arm elevation in the scapular plane to 90° in the sitting position, B, shoulder flexion to 90° in the side-lying position, and C, shoulder external rotation in the side-lying position.

UT:LT. Participants were then instructed to maintain the scapular-neutral position without scapular winging and tipping and were provided with EMG biofeedback and oral or tactile cues in a sitting position with their upper extremities at their sides.[7] When participants could demonstrate the scapular-neutral position without oral or tactile cues, they started to perform the training exercises. During training, lines of the baseline ratio of UT:LT and the real-time ratio of UT:LT were displayed on a monitor using the LabChart 8 software. While the exercises were being performed, participants were instructed to control their scapula to maintain their real-time ratio of UT:LT below the line of the baseline ratio with oral or tactile cues.[7]

Strength Training. The strengthening group was not provided with EMG biofeedback. The training intensity was 5 or 6 (*hard*) on the modified RPE scale with participants using the dumbbells. Oral or tactile cues were only provided to participants to correctly perform the exercises without compensatory movement but were not related to scapular position or movement.

Data Analysis

The TMS Variables. The corticospinal data were calculated using LabChart 8 and a customized LabVIEW 17.0 (National Instruments) program. The EMG amplitudes of the MVICs of the LT and SA were calculated by determining the root mean square of the middle 3 seconds of each trial and were averaged across 3 trials. Peak-to-peak amplitudes of the MEPs of the LT and SA were calculated and averaged across 20 trials. The peak-to-peak MEP amplitude was normalized by the root mean square amplitude of the MVIC. The *duration of CSP* was defined as the duration (in milliseconds) between the onset of MEP (above 2 SDs of prestimulus activity) and the recurrence of EMG activity (above the mean of prestimulus activity) and was averaged across 20 trials.

Scapular Muscle Activation and Kinematics. In accordance with recommendations of the International Society of Biomechanics, we calculated the humerothoracic and scapulothoracic (scapular) motions using the following Euler sequences: plane of elevation, elevation, and axial rotation for humerothoracic motion and internal/external rotation, upward/downward rotation, and posterior/anterior tilting for scapular motion.[22] A customized LabVIEW 17.0 program was used to calculate the angle of scapular internal/external rotation, upward/downward rotation, and anterior/posterior tilt at 30°, 60°, 90°, and 120° of the humerothoracic elevation (humeral elevation) angle in the raising and lowering phases.

All raw EMG data collected during arm elevation were bandpass filtered (20–500 Hz) and processed by taking the root mean square with a window of 50 milliseconds, using a customized LabVIEW 17.0 program. The maximum amplitudes of root mean square EMG data during arm elevation at the pretest were calculated by averaging across a window of 100 milliseconds around the peak value. The maximum EMG amplitudes during arm elevation at the pretest were used to normalize the EMG data collected at the pretest and posttest stages. The average of root mean square EMG data for each muscle was calculated over 30°–60°, 60°–90°, and 90°–120° of humeral elevation in the raising and lowering phases and normalized by the maximum amplitude at the pretest. The ratios of UT:LT and UT:SA during the raising and lowering phases at increments of 30°–60°, 60°–90°, and 90°–120° of humeral elevation were also calculated.

Statistical Analysis

A 2-way, mixed-design analysis of variance (ANOVA) with factors of group (scapular orientation and strengthening) and time (pretest and posttest) was used to determine the differences in the TMS variables between groups at the pretest and posttest. For scapular kinematics and EMG, a 3-way mixed-design ANOVA with factors of group (scapular orientation and strengthening), time (pretest and posttest), and humeral elevation angle (30°–60°, 60°–90°, and 90°–120° for EMG and 30°, 60°, 90°, and 120° for kinematics) were used to determine the differences between groups. If a 2-way or

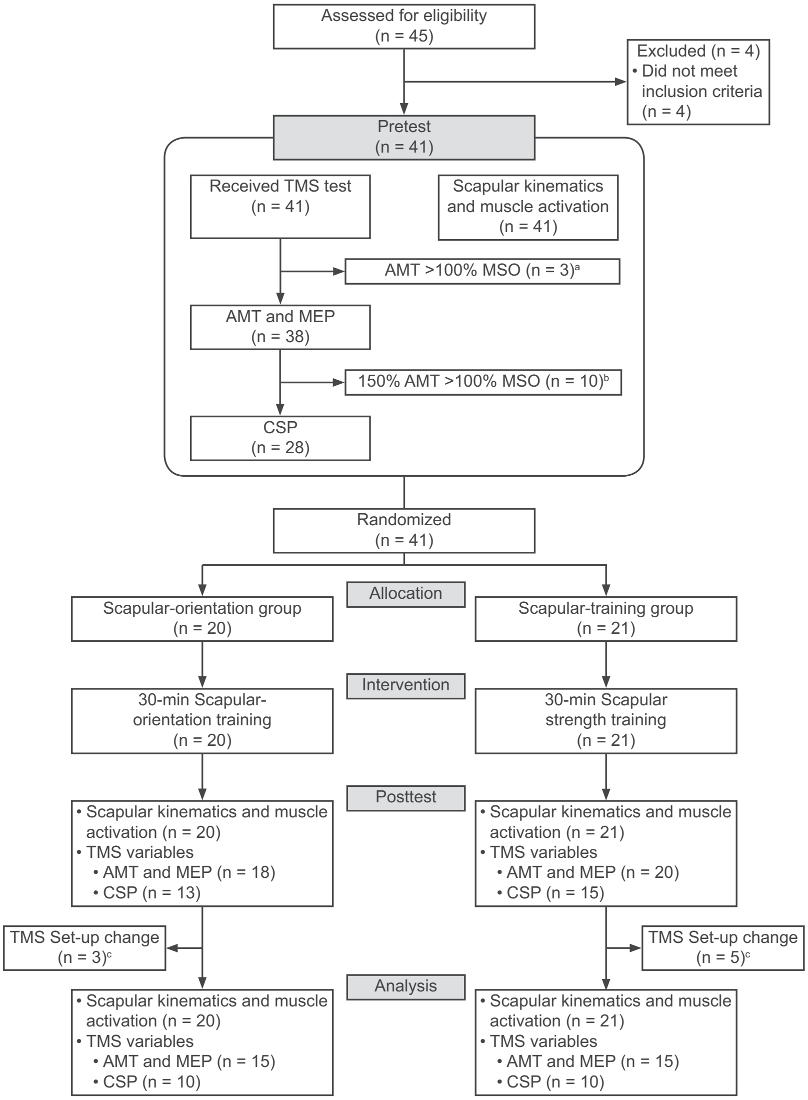

Figure 2. Flowchart of the study. [a] All participants (n = 41) received the measurement of transcranial magnetic stimulation (TMS) in the pretest. Three participants did not demonstrate the defined responses (>0.1 mV in 5 of 10 trials) even at 100% of maximum stimulator output (MSO). Therefore, their active motor threshold (AMT) and motor-evoked potential (MEP) were not available. [b] Among those providing AMT and MEP (n = 38), 10 had high AMT, so their testing intensity (150% AMT) of cortical silent period (CSP) was >100% MSO. Therefore, their CSP was not available. [c] We changed TMS setup after we recruited 8 participants, so we excluded the first 8 participants from analysis.

3-way interaction effect was present, a post hoc pairwise comparison was used to examine the differences between groups, angles, or times. The α level was set at .05. The effect size was represented by partial η^2 (η_p^2), with cutoff points at 0.01, 0.06, and 0.14 indicating a *small*, *medium*, and *large effect*, respectively.[28] We used SPSS 24.0 (IBM Corp) for all statistical analyses.

RESULTS

A total of 41 recreational overhead athletes were recruited and randomly allocated to the scapular-orientation (n = 20) and strengthening (n = 21) groups. No differences in patient characteristics between the 2 groups were noted (Table). No participant reported pain during training. Given changes in the TMS setup during the experiment, 8 participants were excluded from the analysis of TMS variables. Three participants were excluded because their AMT or 120% of AMT was $>$100% MSO of TMS. The CSP was not available in 10 participants because their 150% AMT was $>$100% MSO. Thus, we analyzed 30 participants for AMT and MEP (15 participants in each group) and 20 participants for CSP (10 in each group; Figure 2).

The TMS Variables

In both groups, the MEPs of the LT and SA increased after training (time effect: $F_{1,28} = 10.058$, $P = .004$, $\eta_p^2 = 0.264$ and $F_{1,28} = 5.242$, $P = .030$, $\eta_p^2 = 0.158$, respectively) with no group or interaction effect ($F_{1,28}$ range, 0.001–0.053; P range, .40–.98; $\eta_p^2 < 0.002$; Figure 3A and B). No group, time, or interaction effect was noted in AMT and CSP of the LT ($F_{1,18}$ range, 0.028–0.488; P range, .49–.87; $\eta_p^2 = 0.002$–0.026 and $F_{1,28}$ range, 0.115–1.761; P range, .20–.74; $\eta_p^2 =$ 0.004–0.059; Figure 3C and D).

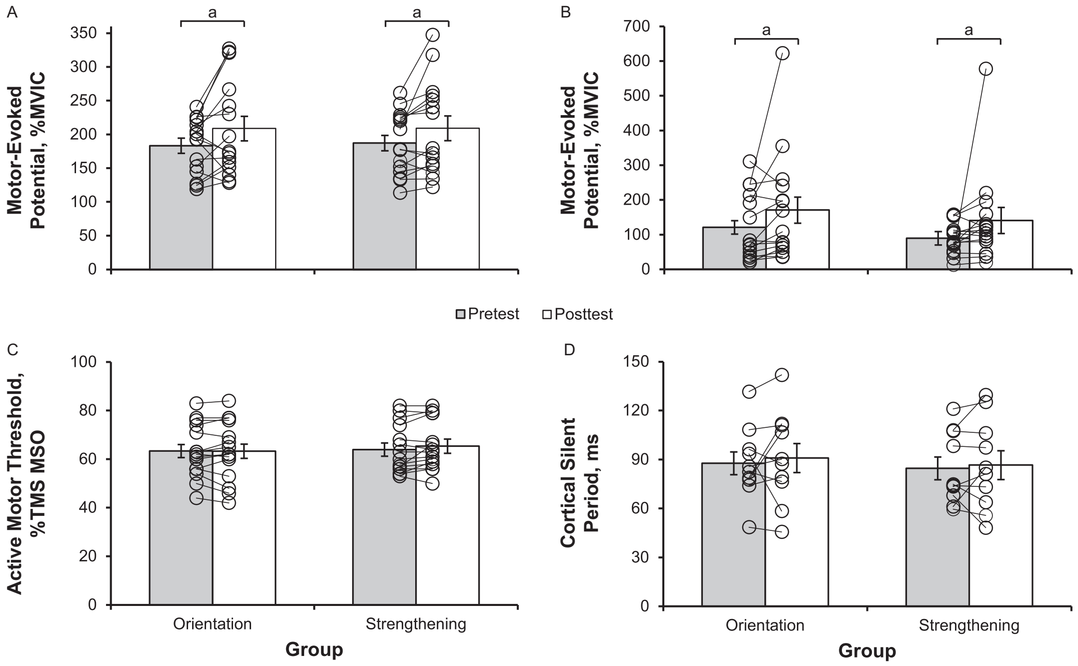

Figure 3. Individual data and bar graphs with means and SEs of transcranial magnetic stimulation (TMS) variables at pretest and posttest in the scapular-orientation and strengthening groups. A, Motor-evoked potential at 120% of active motor threshold of the lower trapezius (LT). B, Motor-evoked potential of the serratus anterior. C, Active motor threshold of the LT. D, Cortical silent period of the LT. Motor-evoked potential was normalized by maximal voluntary isometric contraction (MVIC). Abbreviation: MSO, maximum stimulator output. [a] Time effect (*P* < .05).

Scapular Kinematics

The scapular upward rotation increased after the 30-minute scapular-orientation and strength training (time effect: $F_{1,39} = 4.972$, $P = .03$, $\eta_p^2 = 0.113$) with an angle effect ($F_{7,273} = 922.476$, $P < .001$, $\eta_p^2 = 0.959$), but no other main or interaction effect ($F_{7,273}$ range, 0.503–2.213; P range, .11–.56; η_p^2 range, 0.013–0.054 and $F_{1,39}$ range, 0.558–0.594; P range, .45–.46; η_p^2 range, 0.014–0.015) was observed (Figure 4A and B). Except for angle effects ($F_{7,273}$ range, 14.336–104.605; $P < .001$; η_p^2 range, 0.269–0.728), no time, group, or interaction effect was observed in posterior tilt and internal rotation ($F_{7,273}$ range, 0.233–1.745; P range, .10–.98; η_p^2 range, 0.006–0.043 and $F_{1,39}$ range, 0.074–2.201; P range, .15–.79; η_p^2 range, 0.002–0.053; Figure 4C through F).

Scapular Muscle Activation

An angle effect was observed in all muscles and ratios of UT:LT and UT:SA ($F_{5,195}$ range, 6.945–217.802; $P \leq .003$; η_p^2 range, 0.151–0.848; Figure 5). Participants in both groups showed increased muscle activation of the LT after training (time effect: $F_{1,39} = 45.174$, $P < .001$, $\eta_p^2 = 0.537$; time by angle effect: $F_{5,195} = 3.673$, $P = .03$, $\eta_p^2 = 0.086$). Post hoc comparison indicated that LT activation increased from pretest to posttest at all humeral-elevation angles ($P \leq .001$; Figure 5C and D). A time by group effect was also noted ($F_{1,39} = 5.088$, $P = .03$, $\eta_p^2 = 0.115$). Post hoc analysis indicated that, although both the scapular-orientation and strengthening groups increased LT activation from pretest to posttest ($P <$ .001 and $P = .003$, respectively), the scapular-orientation group demonstrated higher LT activity levels than did the strengthening group at posttest ($P = .03$; Figure 5C and D). No other main or interaction effect ($F_{5,195}$ range, 0.627–0.878; P range, .45–.55; η_p^2 range, 0.016–0.022 and $F_{1,39} = 3.868$; $P = .06$; $\eta_p^2 = 0.090$) was observed for the LT.

The muscle activation of the SA increased after training in both groups (time effect: $F_{1,39} = 18.815$, $P < .001$, $\eta_p^2 = 0.325$), particularly at specific angles (time by angle effect: $F_{5,195} = 6.069$, $P = .005$, $\eta_p^2 = 0.135$; Figure 5E and F). Post hoc analysis indicated that SA activation increased at 30°–60°, 60°–90°, and 90°–120° of humeral elevation during the raising phase and 120°–90° during the lowering phase ($P \leq$ .03). No other main or interaction effect ($F_{1,39}$ range, 0.413–1.416; P range, .24–.52; η_p^2 range, 0.010–0.035 and $F_{5,195}$ range, 0.900–2.241; P range, .05–.48; η_p^2 range, 0.023–0.0554) was observed for the SA (Figure 5E and F). No main or interaction effect was noted in the UT ($F_{5,195}$ range, 0.333–2.101; P range, .12–.80; $\eta_p^2 = 0.008$–0.051 and $F_{1,39}$ range, 0.446–1.729; P range, .20–.51; η_p^2 range, 0.011–0.042; Figure 5A and B), UT:LT ratio ($F_{5,195}$ range, 0.318–1.621; P range, .16–.90; η_p^2 range, 0.008–0.040 and $F_{1,39}$ range, 1.052–3.881; P range, .06–.31; η_p^2 range, 0.026–0.091), or UT:SA ratio ($F_{1,39}$ range, 1.208–3.542; P range, .07–.28; η_p^2 range, 0.030–0.083 and $F_{5,195}$ range, 0.115–2.234; P range, .05–.99; η_p^2 range, 0.003–0.054).

DISCUSSION

In previous studies, individuals with SIS demonstrated altered scapular muscle activation and kinematics and altered corticospinal excitability of scapular muscles.[2–4,11] Although

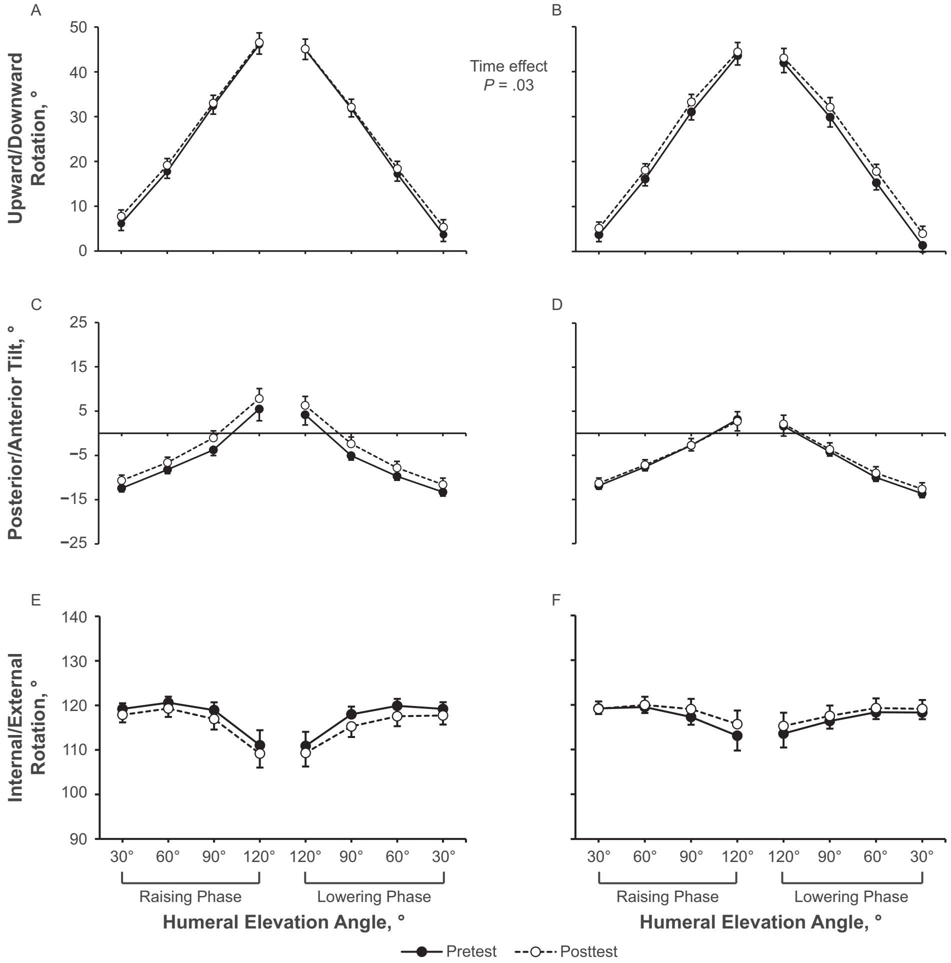

Figure 4. Scapular kinematics (means and SEs) during arm elevation at pretest and posttest in the scapular-orientation and strengthening groups. A and B, Upward/downward rotation. C and D, Posterior/anterior tilt. E and F, Internal/external rotation. A time effect was found in upward rotation ($P = .03$).

scapular-orientation and strength training have been shown to improve scapular kinematics and muscle activation, no researchers have investigated whether scapula-focused exercise protocols can change the corticospinal excitability of individuals with SIS. Our hypotheses were partially supported by the results; after a 30-minute training protocol, both the scapular-orientation and strengthening groups showed increased corticospinal excitability and improvement in scapular control during arm elevation, including increases in scapular upward rotation, LT activation, and SA activation. Moreover, compared with strength training, scapular-orientation training provided greater increases in LT activation.

We observed an increase in MEP, with a large effect size, after 1 session of the scapular-orientation or strength training. Similar findings for healthy individuals were reported in previous motor-skill training studies.[13,14] Purely strengthening exercises, however, have shown inconsistent effects on the corticospinal excitability of healthy individuals, but authors of a recent review concluded that strength training may also increase excitability and induce cortical reorganization.[15,29] In addition, the metronome that we used to standardize the movement speed of the exercises could also provide feedback during strength training, which may help induce corticospinal changes.[13]

Altered corticomotor excitability in individuals with musculoskeletal problems has been linked to changes in neuromuscular control and chronic symptoms.[10,12] Decreased corticospinal excitability (increased AMT) of the LT and SA has been observed in individuals with SIS.[11] Whereas motor threshold is thought to reflect membrane excitability, serving as a marker of intrinsic neuronal excitability, MEP amplitude represents the strength of synaptic transmission, and changes in MEP amplitudes have been termed *long-term potentiation-like* and *long-term depression-like plasticity*.[30,31] In our study, the increases in MEP after the 30-minute training protocols demonstrated induction of long-term potentiation-like plasticity, but no change in the AMT indicated that the 30-minute protocols did not induce intrinsic neuronal plasticity. Jensen et al found decreases in AMT after a 4-week motor-skill training protocol.[14] Therefore, future work should be done to investigate whether a short- or long-term scapula-focused training protocol can induce intrinsic plasticity to reverse the decreased neuronal excitability that has been observed in individuals with SIS.

A few researchers have investigated corticomotor adaptation after interventions in individuals with musculoskeletal problems. They found that specific exercises, including isolated contraction training with ultrasound biofeedback, motor-control training, or sling exercise, could change corticomotor representation of multifidus and transverse abodomini or

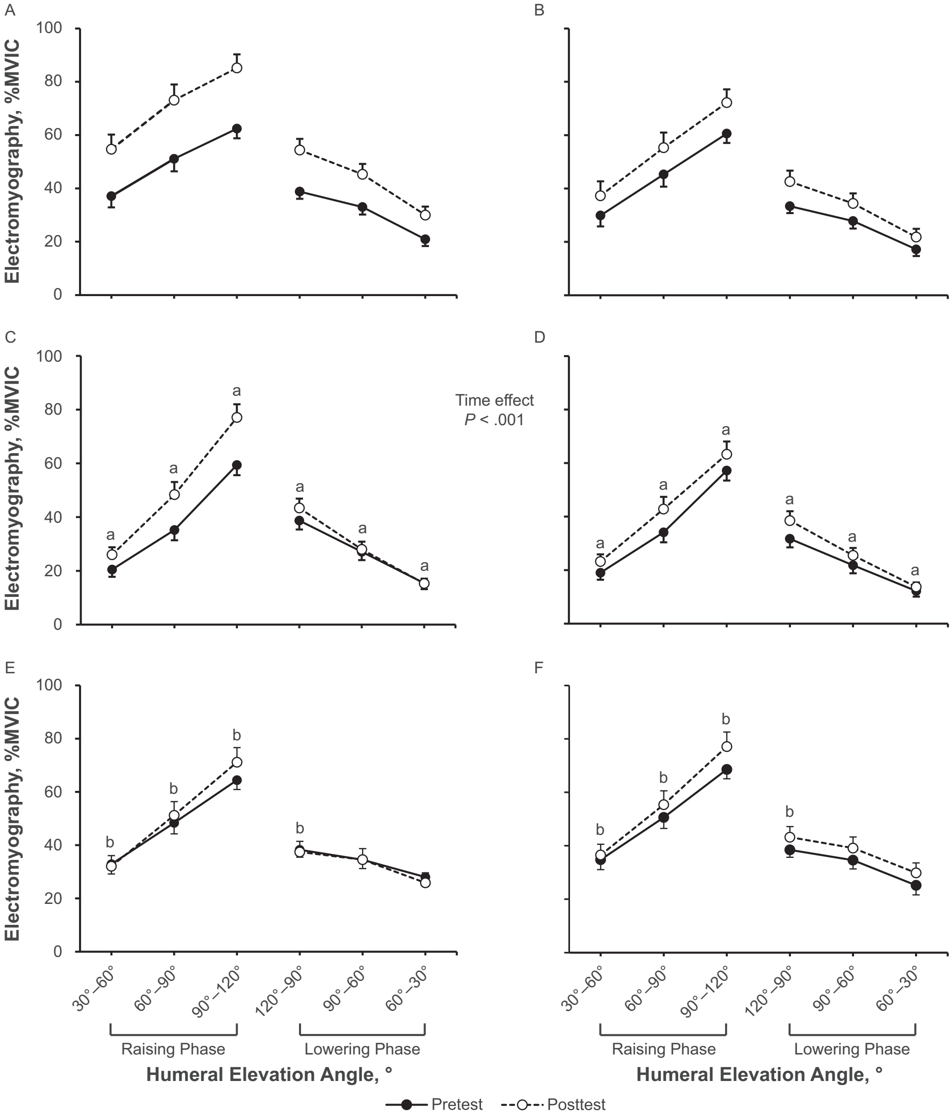

Figure 5. Muscle activation (means and SEs) during pretest and posttest arm elevation of the upper trapezius in, A, scapular-orientation and, B, strengthening groups; lower trapezius in, C, scapular-orientation and, D, strengthening groups; and serratus anterior in the, E, scapular-orientation and, F, strengthening groups. [a] Difference between groups at posttest ($P = .03$). [b] Difference between pretest and posttest ($P < .05$).

decrease excitability of superficial muscles (UT and superficial multifidus) in individuals with chronic low back pain or neck pain.[32–35] We also observed corticospinal adaptation after scapula-focused exercises. Although the feedback or cues for scapular muscle activation and movement were not provided during strength training, 2 of the 3 exercises in the protocol have been demonstrated to specifically induce high activation of the LT and SA with low activation of the UT.[5] Therefore, the individuals with SIS in the strengthening group also demonstrated corticospinal adaptation after training.

Researchers have found decreased intracortical inhibition, termed *cortical disinhibition*, in individuals with musculoskeletal problems, such as low back pain and lateral epicondylalgia, by testing short-interval intracortical inhibition.[36–38] Massé-Alarie et al reported that the intracortical inhibition in individuals with low back pain can be temporarily restored by applying 1 session of repetitive peripheral magnetic stimulation.[38] Future work may need to be done to investigate whether individuals with SIS also demonstrate cortical disinhibition, by testing short-interval intracortical inhibition, and whether scapula-focused exercises can also restore the intracortical inhibition.

In numerous studies, researchers have investigated the effects of various scapula-focused exercises on scapular control with different study designs. In individuals with SIS, scapular kinematics and muscle-activation patterns could be improved after 1 session of EMG biofeedback training or a 10-week scapular motor-control training protocol and after a short-term scapular strength-training protocol (8–12 weeks).[7–9] We observed similar results; both scapular-orientation and strength training increased scapular upward rotation, SA activation, and LT activation during arm elevation, with medium to large effect sizes. The SA and LT formed a force couple for scapular upward rotation.[3,4] Therefore, with increases in SA and LT activation, scapular upward rotation also increased after training, which may have increased the subacromial space to prevent impingement. In addition, the scapular-orientation group showed higher levels of LT activation after training compared with the strengthening group, with a medium effect size. Therefore, biofeedback and cues for scapular control are recommended when conducting scapula-focused exercises.

This study had several limitations. The first author (S.L.L.) was the assessor and physical therapist and was not blinded. Although most of the outcomes were measured objectively using research instruments, interaction with participants during training may still have biased the training effects. In addition, because we only included young recreational overhead athletes (age range, 20–40 years) with scapular dyskinesis, our results cannot be generalized to the general population of people with SIS. Electromyographic biofeedback may not be available in clinical settings, and therefore, studies should be done to investigate whether oral and tactile cues that can be used in a clinical setting have the same effects as EMG biofeedback. Moreover, weight was provided during the scapular-orientation training to facilitate scapular control based on previous studies, so scapular-orientation training may not be pure motor-skill training. The training effects observed in the scapular-orientation group may be mixed effects of both skill and strength training. In addition, we recorded SA MEP when collecting LT MEP but did not determine AMT and the hotspot of the SA. Therefore, the results related to the SA MEP should be interpreted with caution. Future studies should be done to determine the effects of a short- or long-term scapula-focused protocol on corticomotor excitability and investigate the relationship between long-term symptoms and therapy-induced corticospinal adaptation.

CONCLUSIONS

In addition to changed scapular kinematics and muscle activation, individuals with SIS have alterations in corticomotor excitability.[3,4,10,11] In our study, both 30-minute protocols of scapula-focused exercise with (scapular-orientation training) and without (strength training) EMG biofeedback immediately increased the corticospinal excitability of the recreational overhead athletes. Although both the scapular-orientation and strengthening groups increased scapular upward rotation, LT activation, and SA activation after training, the scapular-orientation group had higher LT activation than the strengthening group. Therefore, during scapula-focused training, feedback and cues for scapular motion and muscle contraction are still recommended. Future studies should be done to investigate short- or long-term corticomotor adaptation after interventions and its relationship with pain and function.

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