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Single-Session Video and Electromyography Feedback in Overhead Athletes With Scapular Dyskinesis and Impingement Syndrome

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Context: Subacromial impingement syndrome (SIS) is associated with scapular dyskinesis, or imbalanced scapular muscle activity. Evidence has shown that feedback can improve scapular control in patients with SIS. However, it is unknown whether real-time video feedback or electromyography (EMG) biofeedback is optimal for improving scapular kinematics and muscle activity during a functional task.

Objective: To compare the effects of video and EMG feedback sessions on absolute muscle activity (upper trapezius [UT], lower trapezius [LT], serratus anterior), muscle balance ratios (UT/LT, UT/serratus anterior), and scapular kinematics (anterior-posterior tilt, external-internal rotation, upward rotation) in SIS participants during arm elevation and lowering.

Design: Randomized controlled clinical trial.

Setting: Research laboratory.

Patients or Other Participants: Overhead athletes who were diagnosed with SIS and who also exhibited scapular dyskinesis (N = 41).

Main Outcome Measure(s): Three-dimensional kinematics and EMG were recorded before and after feedback training.

Results: Lower trapezius muscle activity increased (4.2%–18%, $P < .011$) and UT/LT decreased (0.56–1.17, $P < .013$) in the EMG biofeedback training group as compared with those in the video feedback training group. Scapular upward rotation during arm elevation was higher in the video group than in the EMG group after feedback training (2.3°, $P = .024$).

Conclusions: The EMG biofeedback improved muscle control and video feedback improved the correction of scapular upward rotation in patients with SIS.

Trial Registration Number: ClinicalTrials.gov: NCT03252444.

Key Words: EMG biofeedback, muscle performance, scapular kinematics

Key Points

- The immediate retention effect of feedback training was positive: decreases in upper trapezius (UT)/lower trapezius (LT) and UT/serratus anterior muscle ratios, UT muscle activity, and scapular internal rotation.
- Compared with the video feedback, electromyography biofeedback training decreased (ie, improved) muscle activity in the UT/LT and UT/serratus anterior muscle balance ratios and increased LT muscle activity in those with SIS.
- Compared with the electromyography biofeedback training, video feedback produced higher scapular upward rotation among patients with SIS.

Subacromial impingement syndrome (SIS) is defined by compression of the rotator cuff structures, the long head of the biceps tendon, and the bursa beneath the coracoacromial arch during arm elevation[1–3] and is a common health problem.[4–6] Patients with SIS experience shoulder pain and range-of-motion limitations, which lead to decreased functional ability.[7–11] The scapulothoracic joint is believed to be essential to restoring function in individuals with SIS.[7–11]

Altered scapular kinematics and associated muscular activities have been proposed as possible mechanisms of SIS.[2,5,9,10] During arm movements, decreased scapular posterior tilt, external rotation, and upward rotation have been found in participants with SIS.[5,9,10] Additionally, these altered kinematics may be associated with the concurrent muscle activation findings of decreases in the serratus anterior (SA) and lower trapezius (LT) and an increase in the upper trapezius (UT).[5,9,10] Thus, control of scapular kinematics and muscle performance are proposed treatment targets for patients with SIS.[2,12–15]

Impaired muscle control can result in muscle performance deficits, which are contributing factors to SIS.[5,12,14,16,17] Scapular muscle neuromuscular control is believed to be crucial for maintaining optimal scapular alignment.[14,18–20] While receiving electromyography (EMG) biofeedback training, participants were able to selectively activate divisions of the SA and trapezius segments (decrease muscle balance ratios in the UT/LT and

UT/SA) during tasks such as side-lying external rotation, shoulder forward flexion, and typing.[15,18,21,22] After receiving video feedback training, participants with SIS demonstrated increased scapular protraction and upward rotation during shoulder forward elevation to 60° and 90°.[20] Although the results of feedback training have been positive, the diversity of methods and study participants make it difficult to draw firm conclusions about feedback training.[15,18–22]

Whether focusing on scapular muscle activity to further adjust scapular alignment or correcting scapular alignment with the aid of video has the most beneficial effects for SIS patients is unknown. Thus, our aim was to compare the immediate effects of video feedback and those of EMG biofeedback on absolute muscle activity (UT, LT, SA), muscle balance ratios (UT/LT, UT/SA), and scapular kinematics (anterior-posterior tilt, external-internal rotation, and upward rotation) in patients with SIS during arm elevation and lowering.

METHODS

Study Design

This was a laboratory-based, cross-sectional study.

Participants

According to previous studies,[1,15,23] a total sample size of 40 participants was calculated to provide 80% power with effect sizes of 0.91, 0.86, and 0.94 to detect differences in scapular posterior tilt (3.7°), UT/LT ratio (31%), and LT muscle activity (5.98% of maximal voluntary isometric contraction; MVIC), respectively. Diagnosis of overhead athletes with SIS was based on positive results on at least 2 of the following 5 impingement tests: (1) Neer impingement test, (2) Hawkins-Kennedy impingement test, (3) empty can test, (4) external resisted test, (5) pain during rotator cuff palpation.[24] Additionally, all participants with SIS had medial border prominence dyskinesis.[25] Volunteers were excluded from the study if they had any of the following conditions: (1) history of shoulder dislocation, fracture, or surgery within the past year; (2) history of direct contact injury to the neck or upper extremities within the past month; (3) glenohumeral joint instability (positive apprehension test, sulcus sign); (4) neurologic disorder; or (5) pain (visual analogue scale rating $>$ 5) during the experimental tasks. The National Taiwan University Hospital Human Subject Research Ethics Committee approved this study. All participants gave written informed consent before data collection began.

Instrumentation

The 3Space FASTRAK (Polhemus Inc, Colchester, VT), an electromagnetic motion-analysis system with Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL), was used to collect 3-dimensional scapular kinematics. According to the manufacturer, the system is accurate to 0.8 mm and 0.15°. A previous validity study[26] showed that the FASTRAK could be used for collection of kinematic data under 120° of arm elevation in lean young participants. Three electromagnetic sensors were used for kinematic tracking of the scapula. The first sensor was attached to the sternum, and the second was attached to the flat bony surface of the acromion with adhesive tape. The third sensor was attached to the distal humerus with hook-and-loop straps. Local coordinate systems were marked with a stylus by an experienced physical therapist as follows: sternal notch, xiphoid process, seventh cervical vertebrae, eighth thoracic vertebrae, 12th thoracic vertebrae, acromion, anterior glenohumeral joint, posterior glenohumeral joint, root of the spine of the scapula, inferior angle of the scapula, lateral epicondyle, and medial epicondyle.

Following the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guidelines,[27] we arranged the surface (s)EMG assemblies to consist of pairs of silver chloride circular (recording diameter of 10 mm) surface electrodes (The Ludlow Company LP, Chicopee, MA) with an interelectrode (center-to-center) distance of 20 mm, and a Grass AC/DC amplifier (model 15A12; Astro-Med Inc, West Warwick, RI) with a gain of 1000, a common mode rejection ratio of 86 dB at 60 Hz, and a bandwidth (–3 dB) of 10 to 1000 Hz. The sEMG data were collected at 1000 Hz per channel using a 16-bit analog-to-digital converter (model MP 150; BIOPAC Systems Inc, Goleta, CA). Surface EMG electrodes were placed on the UT, LT, and SA of the involved shoulder. Electrodes for the UT were placed midway between the acromion and the seventh spinous process of the cervical vertebrae. The LT was palpated obliquely upward and laterally along the line between the intersection of the spine of the scapula and the seventh spinous process of the thoracic vertebrae. Electrodes for the SA were placed anterior to the latissimus dorsi and posterior to the pectoralis major. The reference electrode was placed on the ipsilateral clavicle. Full bandwidth sEMG data captured by the data-acquisition software (AcqKnowledge; BIOPAC Systems Inc) were reduced using a root mean square algorithm to produce sEMG envelopes with an effective sampling rate of 50 samples. A trigger point was used at the beginning of the movements to synchronize 3-dimensional kinematic data and EMG data.

Feedback Training

Participants were randomly assigned to the video feedback or EMG biofeedback group by block randomization (4 participants per block) after baseline data collection. During the experiment, male participants removed their shirts and female participants wore halter tops. Before the main experiment, surface EMG electrodes and FASTRAK kinematic sensors were attached to the participants.

The participants learned to use constant feedback to correct their scapular-muscle activation or scapular kinematics throughout the experiment. Both groups received feedback, either from video or EMG. The scapular-correction training consisted of 2 sections, learning and training. In the learning section, the participants learned to position the scapula in neutral while in the resting position (arms by sides) and were familiarized with the feedback. *Scapular neutral position* was defined as both scapulae being relatively symmetric with no prominence of the scapular medial border or inferior angle.[28] The video feedback group was instructed to decrease the prominence of the scapular inferior angle and medial border on the screen by placing the scapula tightly against the rib cage

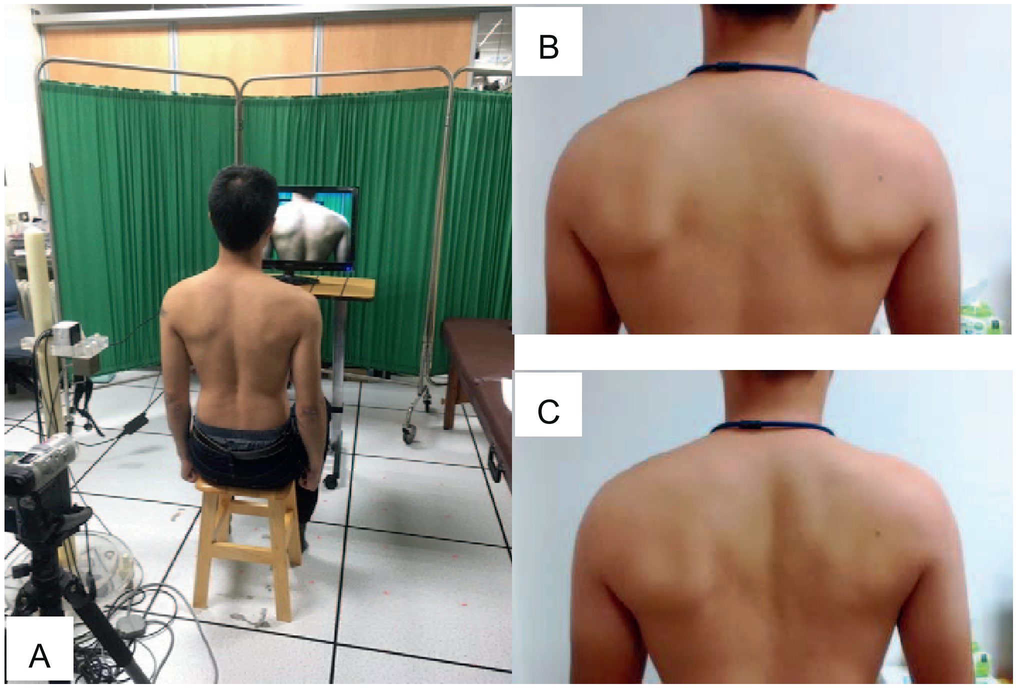

Figure 1. Video feedback display image. A, A display screen was placed 1 m in front of the participant; a video camera was placed 2 m behind the participant. B, The participant was asked to focus on maintaining the scapular medial border and inferior angle on the rib cage (right scapula). C, The prominence of the medial border of the right scapula decreased in posttraining compared with that in pretraining.

(Figure 1). The EMG biofeedback group was instructed to focus on the UT/LT muscle balance ratio signals. The goal was to keep the activity ratio below a specified threshold. The threshold was based on the range of 1 standard deviation (SD) of the pretest ratio average data (Figure 2). The threshold for scapular control learning was based on a pilot study conducted before the present study, which identified that the 1.5 SD value was too difficult for participants, whereas the 0.5 SD value was too easy. Thus, we chose 1 SD as the threshold.

The participants practiced in the resting position until they were able to successfully achieve the stated goals: either decreasing the prominence of the medial border of the scapula (video feedback group) or lowering the magnitude of muscle ratios below the threshold (EMG biofeedback group) 3 times in a row. When the participants were able to correct the scapula to neutral while resting, they were instructed to proceed to the training section to correct the scapula during arm elevation and lowering. Their goals were also to decrease the prominence of the scapula on the video feedback or to maintain the UT/LT

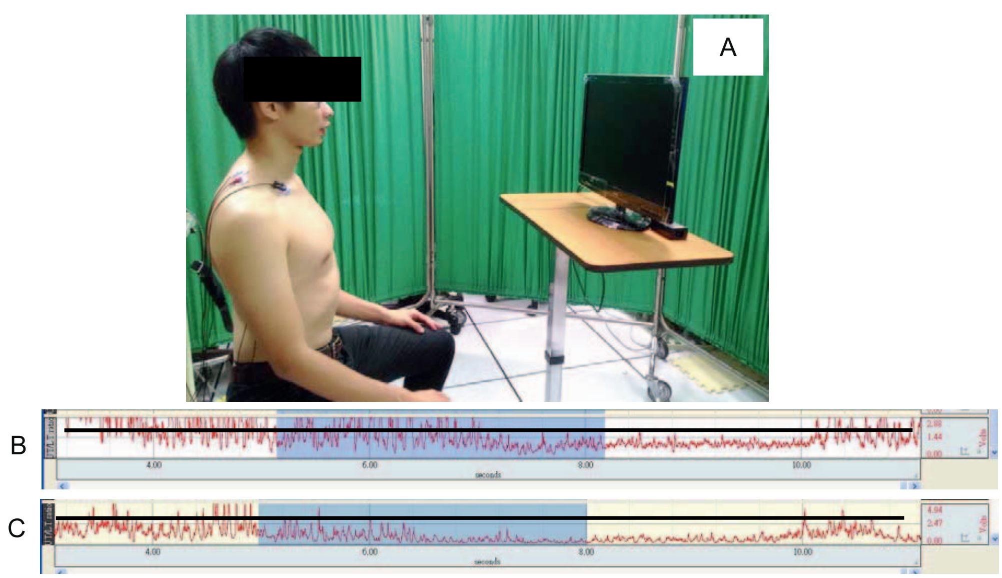

Figure 2. The electromyography biofeedback display image. A, A display screen was placed 1 m in front of the participant. B, The participant was asked to focus on the threshold (black line) and to keep the signal below the threshold (before training). C, Lowering of the magnitude of muscle ratios below the threshold (shadowed area) was demonstrated during posttraining as compared with pretraining.

muscle balance ratio signals below a threshold. The arm-elevation and -lowering task included arm elevation in the scapular plane to 180° within 3 seconds and lowering within 3 seconds. During arm elevation and lowering, male participants held a 1-kg dumbbell and female participants held a 0.5-kg dumbbell. Oral cues such as "Retract the scapula," "Do not overshrug the shoulder," "Relax your shoulders," and "Slightly squeeze the muscles between the scapula" and tactile cues were given to the participants as supplemental instructions in both groups throughout the experiment. Participants were allowed to practice for 9 trials in 3 blocks of 3 trials per block. A 1-minute rest period was allowed between blocks.

Time-Point Measures

Muscle activity (UT, LT, SA), muscle balance ratios (UT/LT, UT/SA), and scapular kinematics (anterior-posterior tilt, external-internal rotation, upward rotation) were collected during the arm-elevation and -lowering task. The arm-elevation and -lowering task was conducted 3 times each before and after the feedback intervention with and without the feedback condition.

Data Reduction

The raw kinematic data were low-pass filtered at a 6-Hz cutoff frequency and converted into anatomically defined rotations. In general, we followed the International Society of Biomechanics guidelines (https://isbweb.org/images/documents/standards/Wu%20et%20al%20J%20Biomech%2038%20(2005)%20981%E2%80%93992.pdf) for constructing a shoulder-joint coordinate system. Scapular orientation relative to the thorax was described using a Euler angle sequence of rotation about Z_s (internal-external rotation), rotation about Y'_s (downward-upward rotation), and rotation about X''_s (posterior-anterior tilt). We used scapular internal rotation, upward rotation, and anterior tilt in the final analyses.

Full bandwidth sEMG data captured by data-acquisition software (AcqKnowledge) were reduced using a root mean square algorithm to produce sEMG envelopes with an effective sampling rate of 50 samples. The EMG data for each muscle were the averages of 3 trials. The mean sEMG amplitude of each muscle, reported as a percentage of MVIC, was used to display the normalized activity of the UT, LT, and SA. The MVIC for the UT muscle was measured during resisted shoulder flexion. Participants were seated with the shoulder flexed to 90° and resistance applied to the distal arm.[29] For the MVIC measurement of the LT muscle, participants lay prone with the test arm abducted in line with the muscle fibers. Resistance was applied against further elevation. For the MVIC measurement of the SA muscle, participants were seated with the arm elevated to 135°. Resistance was applied to the distal upper arm against further elevation.[30] The MVICs were collected during 3 trials of 5 seconds each, with 1-minute rest intervals between trials. Muscle balance ratios were calculated by dividing the adjusted UT muscle activity by the adjusted LT and SA muscle activity. Muscle activity was recorded during 0° to 30°, 30° to 60°, 60° to 90°, 90° to 120°, and >120° of arm elevation and lowering.

Statistical Analysis

We used SPSS (version 20.0; IBM Corp, Armonk, NY) for data analysis. The Shapiro-Wilk test was performed to confirm normal distribution of the kinematic and EMG data. Three-way mixed analysis of variance was conducted for scapular kinematics and EMG outcomes, with factors of condition (pretraining, posttraining, post without feedback), group (video feedback, EMG biofeedback), and arm-elevation phase (phases of the kinematic data at raising 30°, raising 60°, raising 90°, raising 120°, lowering 120°, lowering 90°, lowering 60°, and lowering 30°; and muscle EMG data at raising 0°–30°, raising 30°–60°, raising 60°–90°, raising 90°–120°, raising >120°, lowering >120°, lowering 120°–90°, lowering 90°–60°, lowering 60°–30°, and lowering 30°–0°). A Bonferroni correction was used to adjust the α level, which was set at .05. If the data did not meet the normality assumptions, nonparametric tests were conducted for the measures.

For nonparametric data, we used the Friedman test and Mann-Whitney U test to compare outcomes between conditions and groups. For the between-groups analyses, we compared the between-groups values for different elevation angles and time (pretraining, posttraining, post without feedback) separately; thus, the adjusted P value was .025 (.05/2). For the within-group analyses, we compared time (pretraining, posttraining, post without feedback) at different elevation angles; thus, the adjusted P value was .016 (.05/3). The r family effect sizes were used in the analyses. The scapular kinematic and EMG outcome analyses were conducted in the same manner.

RESULTS

Fifty-four participants were recruited for the study, and 13 participants did not meet the criteria. The remaining 41 participants were randomly allocated to the 2 groups. Twenty participants were assigned to the EMG biofeedback group, and 21 to the video feedback group. Participant characteristics are listed in Table 1.

Muscle Activity

The Mann-Whitney U test was conducted for between-groups differences due to nonnormal distribution. Differences were found in muscle activity and muscle balance ratios. The LT muscle activity was higher in the EMG biofeedback group during the posttraining condition in the 0° to 30°, 30° to 60° (medians = 8.84 and 21.94, P values = .001 and .002, and effect sizes = 0.30 and 0.31, respectively), and 60° to 90° (median = 29.37, P = .002, effect size = 0.32) elevation phase and the 120° to 90° lowering phase (median = 23.45, P = .01, effect size = 0.26; Table 2). In the posttraining-without-feedback condition, LT muscle activity increased in the 0° to 30° and 60° to 90° (medians = 8.67 and 26.75, P values = .011 and .011, and effect sizes = 0.27 and 0.29, respectively) raising phases in the EMG biofeedback group. In addition, in the EMG biofeedback group, the UT/LT muscle balance ratio decreased in the 30° to 60°, 60° to 90° (medians = 1.65 and 1.29, P values = .002 and .013, and effect sizes = 0.15 and 0.16, respectively), and >120° (median = 1.71, P = .013, effect size = 0.15) raising phases in the posttraining condition (Table 3).

Table 1. Participant Characteristics and Clinical Data

Participant Characteristics	Feedback Group: Video (n = 21)	Feedback Group: Electromyography (n = 20)
Sex, males	14	16
	Mean ± SD	
Age	25.9 ± 6.1	27.4 ± 5.2
Height, cm	171.3 ± 9.7	174.0 ± 8.1
Weight, kg	65.3 ± 12.3	72.7 ± 15.1
Shoulder function (of a possible 50)	39.3 ± 4.0	39 ± 4.9
Pain during rest/during sports activity (visual analogue scale)	0.1 ± 0.3/4.4 ± 1.7	0/4.5 ± 1.7
Pain duration, mo	41.1 ± 40.4	53.5 ± 54.1
Sports participation, y	5.7 ± 5.8	7.3 ± 5.3
	No.	
Special test 3+[a]	14	17
Painful side = right	16	17
Right-hand dominant	20	18
Dyskinesis type (I+II/II)[b]	19/2	19/1

[a] At least 3 positive results on the Neer impingement test, Hawkins-Kennedy impingement test, empty can test, external-resisted test, and pain during rotator cuff palpation.

[b] All participants had dyskinesis as indicated by prominence of the medial border. Type I+II reflects combined inferior-angle prominence (type I) and medial-border prominence (type II).

For the video feedback group, nonparametric analyses were used for the outcomes due to nonnormal distribution. In the posttraining conditions, UT activity (median = 35.78, $P < .016$, effect size = 0.10), the UT/LT muscle balance ratio (medians = 0.70–1.39, P values < .0016, effect sizes = 0.14–0.16), and UT/SA ratio (median = 0.14, $P < .016$, effect size = 0.13) decreased as compared with the pretraining condition. We also found declines in the post-without-feedback condition as compared with the pretraining condition, including the UT (medians = 32.24–44.22, P values < .016, effect sizes = 0.18–0.30), UT/LT (medians = 0.73–1.73, P values < .016, effect sizes = 0.12–0.21), and UT/SA (medians = 0.69–1.44, P values < .016, effect size = 0.14–0.17). The LT muscle activity increased (medians = 6.32–15.21, P values < .016, effect sizes = 0.25–0.38) during the lowering phase in the posttraining condition. In the posttraining-without-feedback condition, LT muscle activity (medians = 7.13–21.44, P values < .016, effect sizes = 0.33–0.40) increased significantly. In comparisons of posttest with feedback and without feedback, statistical significance was present for the UT/LT between the conditions (medians = 0.89–1.17, P values < .016, effect sizes = 0.11–0.17). Muscle balance ratios were lower in the posttraining-without-feedback condition than in the post-training-with-feedback condition.

For the EMG biofeedback group, UT muscle activity (median = 29.24–39.17 and 16.15–44.22, P values < .016 and .016, and effect sizes = 0.15–0.23 and 0.10–0.21, respectively), UT/LT (medians = 0.83–1.65 and 1.08–2.29, P values < .016 and .016, and effect sizes = 0.20–0.37 and 0.15–0.31, respectively), and UT/SA (medians = 0.56–1.42 and 0.55–1.27, P values < .016 and .016, and effect sizes = 0.09–0.30 and 0.14–0.21, respectively) decreased in the posttraining and posttraining-without-feedback conditions as compared with the pretraining outcomes. The LT muscle activity was higher in the posttraining condition and posttraining-without-feedback condition (medians = 8.67–23.45 and 9.35–22.91, P values < .016 and .016, and effect sizes = 0.27–0.37 and 0.26–0.37, respectively) than in the pretraining condition. The UT/SA ratio increased during the >120° raising phase in the post-without-feedback condition (median = 0.55, $P = .014$, effect size = 0.10).

Scapular Kinematics

In comparisons of the 2 groups, scapular upward rotation was higher in the video group after feedback training (median = 24.29°, $P = .024$, effect size = 0.19; Table 4). No group differences were present in scapular anterior tilt or internal rotation.

In the video feedback group, scapular internal rotation in the 30° lowering phase was lower in the posttraining condition than in the pretraining condition (median = –5.8°, $P = .003$, effect size = 0.20). A difference was also evident in the posttraining and posttraining-without-feedback conditions; scapular internal rotation was lower in the posttraining condition (median = –3.8°, $P = .009$, effect size = 0.10). However, within-group changes in scapular upward rotation and anterior tilt did not reach significant levels.

In the EMG biofeedback group, scapular upward rotation was lower in the posttraining (medians = 0.13°–30.04°, P values < .016, effect sizes = 0.19–0.22) and posttraining-without-feedback (median = 29.61°, $P < .016$, effect size = 0.19) conditions than in the pretraining condition. In the post-feedback condition, the degree of scapular internal rotation was decreased during the 30° lowering phase (median = –6.36°, $P = .003$, effect size = 0.28). No differences were demonstrated in scapular anterior tilt.

DISCUSSION

The purpose of our study was to compare the immediate effects of video feedback and EMG biofeedback training on scapular kinematics, absolute muscle activity, and muscle balance ratios. In comparison with video feedback, EMG biofeedback performed better in improving LT absolute muscle activity (increases of 4.2%–18.1% of MVIC) and UT/LT muscle balance ratios (decreases of 0.56–1.17) in patients with SIS. In contrast, relative to EMG biofeedback, video feedback showed a higher increase in scapular upward rotation (2.3°).

Based on the kinematic theory of the impingement mechanism,[5,31] our data showed that video feedback can be an appropriate treatment strategy for increasing upward rotation during arm elevation in participants with SIS. Inadequate upward rotation is believed to result in the inability of the greater tuberosity of the humerus to pass beneath the acromion during arm elevation.[5,31] Previous authors[5,31] reported that, compared with healthy control individuals, patients with shoulder pain had decreases of 3° to 7° in scapular upward rotation during arm elevation. Although we found only a 2.3° increase in scapular upward rotation in the video biofeedback group as compared with the EMG biofeedback group, our data also demonstrated a decrease of 3.7° in internal rotation after video feedback training. These combined effects of a 3.7° decrease in

Table 2. **Lower Trapezius Muscle Activity as a Percentage of Maximal Voluntary Isometric Contraction: Median (Between-Groups Effect Sizes, Between-Conditions Effect Sizes Compared With Pretraining) [Minimum, Maximum] in Both Groups**

Feedback	Raising, °					Lowering, °				
Time	0–30	30–60	60–90	90–120	>120	>120	120–90	90–60	60–30	30–0
Video										
Pretraining	5.34 [2.7, 12.1]	13.78 [5.2, 24.3]	20.61 [8.4, 34.6]	28.35 [7.1, 53.2]	34.23 [5.8, 79.3]	25.78 [6.6, 55.8]	14.95 [6.8, 34.6]	11.91 [6.8, 25.9]	9.33 [5.4, 17.5]	4.66 [3.0, 8.1]
Posttraining	6.88 (−0.30, −0.05) [2.7, 13.1]	15.15 (−0.31, −0.04) [6.8, 29.5]	19.26 (−0.32,0.02) [5.4, 35.8]	26.52 (−0.24, 0.03) [4.5, 60.4]	29.71 (−0.20, 0.10) [4.3, 78.2]	22.62 (−0.18, 0.08) [5.7, 55.5]	16.54 (−0.26, −0.06) [6.4, 38.9]	15.21[b] (−0.23, −0.25) [7.8, 40.1]	12.72[b] (−0.24, −0.38) [6.8, 39.3]	6.32[b] (−0.25, −0.34) [2.9, 19.8]
Posttraining without feedback	6.02 (−0.27, −0.11) [2.6, 13.2]	15.37 (−0.23, −0.09) [5.6, 37.4]	20.63 (−0.29, −0.02) [5.5, 37.4]	29.28 (−0.23, −0.01) [3.33, 62.7]	29.63 (−0.20, 0.07) [3.2, 88.2]	24.48 (−0.13, 0.00) [4.8, 64.0]	18.43 (−0.19, −0.16) [6.25, 41.3]	21.44[c] (−0.16, −0.33) [8.0, 34.1]	13.31[c] (−0.22, −0.39) [6.9, 29.2]	7.13[c] (−0.23, −0.40) [3.1, 30.1]
Electromyography										
Pretraining	8.03 [2.7, 12.1]	20.34 [9.2, 31.6]	23.50 [11.0, 47.9]	29.25 [12.2, 85.3]	37.06 [11.9, 99.6]	23.00 [10.0, 57.6]	14.77 [5.5, 37.7]	13.42 [4.8, 30.6]	10.84 [4.8, 25.4]	4.98 [1.9, 12.8]
Posttraining	8.84[a] (−0.30, −0.18) [5.1, 21.1]	21.94[a] (−0.31, −0.16) [15.6, 54.5]	29.37[a] (−0.32, −0.16) [17.1, 80.9]	35.75 (−0.24, −0.08) [19.2, 86.8]	33.22 (−0.20, 0.03) [12.5, 96.5]	26.77 (−0.18, −0.03) [13.3, 91.3]	23.45[ab] (−0.26, −0.27) [11.3, 52.1]	22.83[b] (−0.23, −0.31) [11.4, 46.7]	17.14[b] (−0.24, −0.31) [10.5, 28.8]	8.67[b] (−0.25, −0.37) [5.0, 25.4]
Posttraining without feedback	8.67[a] (−0.27, −0.13) [4.6, 23.1]	18.92 (−0.23, −0.13) [14.0, 54.0]	26.75[a] (−0.29, −0.13) [16.7, 72.6]	33.02 (−0.23, −0.09) [19.6, 93.9]	34.35 (−0.20, 0.00) [15.0, 101.0]	25.32 (−0.13, −0.05) [12.0, 71.1]	22.91[c] (−0.19, −0.26) [11.6, 52.4]	21.96[c] (−0.16, −0.29) [9.6, 46.4]	17.51[c] (−0.22, −0.30) [9.7, 35.0]	9.35[c] (−0.23, −0.37) [5.4, 29.7]

[a] Difference between groups.
[b] Difference between pretraining and posttraining.
[c] Difference between pretraining and posttraining without feedback.

Table 3. **Upper Trapezius:Lower Trapezius Muscle Balance Ratio Medians (Between-Groups Effect Sizes, Between-Conditions Effect Sizes Compared With Pretraining) [Minimum, Maximum] in Both Groups**

Feedback	Raising, °					Lowering, °				
Time	0–30	30–60	60–90	90–120	>120	>120	120–90	90–60	60–30	30–0
Video										
Pretraining	2.38 [0.9, 9.8]	2.16 [0.7, 8.8]	1.95 [0.6, 8.3]	1.97 [0.6, 10.8]	2.05 [0.4, 10.4]	1.67 [0.4, 11.5]	1.97 [0.6, 14.6]	1.79 [0.7, 15.7]	1.41 [0.5, 14.1]	1.26 [0.5, 8.0]
Posttraining	1.42 (0.10, 0.06) [0.7, 6.3]	1.49 (0.15, 0.02) [0.5, 7.9]	1.07 (0.16, 0.00) [0.4, 12.6]	1.39[b] (0.11, 0.14) [0.3, 13.9]	1.52 (0.15, 0.07) [0.5, 9.7]	1.35 (0.09, 0.00) [0.2, 8.6]	1.11[b] (0.11, 0.15) [0.2, 6.9]	1.00[b] (0.01, 0.14) [0.3, 2.6]	0.70[b] (−0.04, 0.17) [0.3,1.9]	0.96[b] (−0.02, 0.16) [0.2, 3.2]
Posttraining without feedback	1.58[c] (0.11, 0.18) [0.6, 5.7]	1.42 (0.12, 0.05) [0.4, 7.4]	1.17[cd] (0.10, 0.12) [0.5, 10.1]	1.73[c] (0.06, 0.14) [0.4, 11.1]	1.3 (0.11, 0.14) [0.5, 10.5]	1.19 (0.00, 0.05) [0.2, 8.4]	0.89[d] (0.01, 0.12) [0.2, 8.4]	0.73[c] (−0.07, 0.18) [0.2, 3.4]	0.79[c] (−0.08, 0.21) [0.2, 2.1]	0.82[c] (−0.11, 0.18) [0.1, 2.9]
Electromyography										
Pretraining	2.84 [1.0, 22.9]	2.20 [0.5, 15.2]	1.91 [0.4, 12.6]	2.02 [0.4, 11.8]	2.14 [0.4, 10.5]	2.11 [0.3, 10.4]	2.19 [0.3, 10.7]	2.38 [0.4, 10.0]	2.07 [0.4, 7.2]	1.59 [0.3, 9.1]
Posttraining	2.04 (0.10, 0.09) [0.8, 19.4]	1.65[ab] (0.15, 0.29) [0.4, 25.6]	1.29[ab] (0.16, 0.29) [0.3, 12.6]	1.46[b] (0.11, 0.20) [0.5, 10.4]	1.71[a] (0.15, 0.10) [0.5, 9.5]	1.42 (0.09, 0.12) [0.4, 7.2]	1.28[b] (0.11, 0.26) [0.4, 8.8]	1.20[b] (0.01, 0.26) [0.5, 8.8]	1.00[b] (−0.04, 0.26) [0.3, 7.2]	0.83[b] (−0.02, 0.37) [0.2, 8.0]
Posttraining without feedback	2.29[c] (0.11, 0.31) [0.7, 23.9]	1.55[ac] (0.12, 0.23) [0.7, 30.6]	1.23[c] (0.10, 0.21) [0.7, 13.0]	1.54[c] (0.06, 0.15) [0.6, 12.3]	1.60 (0.11, 0.11) [0.4, 10.3]	1.27 (0.00, 0.09) [0.3, 9.6]	1.21[c] (0.01, 0.24) [0.4, 10.0]	1.24[c] (−0.07, 0.25) [0.4, 7.4]	1.19[c] (−0.08, 0.27) [0.2, 6.9]	1.08[c] (−0.11, 0.31) [0.3, 6.8]

[a] Difference between groups.
[b] Difference between pretraining and posttraining.
[c] Difference between pretraining and posttraining without feedback.
[d] Difference between posttraining and posttraining without feedback.

Table 4. **Scapular Upward Rotation Degree Medians (Between-Groups Effect Sizes, Between-Conditions Effect Sizes Compared With Pretraining) [Minimum, Maximum] in Both Groups**

Feedback	Raising, °				Lowering, °			
Time	30	60	90	120	120	90	60	30
Video								
Pretraining	10.8 [4.6, 28.8]	24.5 [14.8, 37.3]	35.0 [24.7, 41.9]	43.1 [29.2, 64.9]	40.1 [25.5, 63.8]	29.2 [19.0, 44.8]	16.1 [12.1, 26.8]	4.8 [−0.9, 16.7]
Posttraining	11.8 (0.18, −0.07) [4.4, 25.3]	24.3[a] (0.19, 0.06) [6.5, 36.0]	33.8 (0.09, 0.12) [9.1, 42.5]	42 (−0.04, 0.04) [27.6, 61.1]	40.3 (−0.03, 0.03) [25.1, 64.4]	27.9 (−0.02, 0.03) [20.6, 42.1]	17.5 (0.04, 0.05) [7.9, 27.0]	8.6 (0.13, −0.13) [−3.0, 19.3]
Posttraining without feedback	12.1 (0.19, −0.09) [4.7, 27.7]	24.5 (0.19, −0.01) [14.6, 35.7]	33.8 (0.16, 0.03) [24.7, 41.9]	42.8 (0.00, 0.01) [27.2, 61.5]	40.9 (0.00, 0.01) [25.4, 61.4]	27.5 (−0.02, 0.05) [21.2, 41.5]	14.3 (0.06, 0.08) [5.0, 30.2]	6.9 (0.16, −0.13) [−3.0, 22.8]
Electromyography								
Pretraining	11.2 [4.4, 29.0]	23.6 [12.3, 42.0]	33.6 [16.2, 54.3]	39.1 [20.8, 64.3]	38.6 [19.7, 63.0]	30.3 [16.4, 51.0]	17.0 [10.0, 40.3]	3.0 [−0.9, 24.9]
Posttraining	9.6 (0.18, 0.09) [4.0, 29.7]	20.1[b] (0.19, 0.22) [12.1, 41.1]	30.0[b] (0.09, 0.19) [16.3, 53.3]	40.5 (−0.04, −0.09) [19.3, 65.3]	39.0 (−0.03, 0.00) [18.9, 60.7]	27.8 (−0.02, 0.07) [16.8, 51.7]	15.2 (0.04, 0.15) [7.9, 39.7]	3.8 (0.13, 0.10) [−3.0, 24.2]
Posttraining without feedback	9.7 (0.19, 0.08) [4.3, 29.9]	19.9 (0.19, 0.15) [−21.5, 41.8]	29.6[c] (0.16, 0.19) [16.5, 53.9]	41.6 (0.00, −0.09) [20.3, 63.2]	39.8 (0.00, 0.00) [20.1, 61.2]	29 (−0.02, 0.07) [19.0, 52.2]	14.2 (0.06, 0.16) [4.9, 41.2]	3.3 (0.16, 0.13) [−3.0, 24.5]

[a] Difference between groups.
[b] Difference between pretraining and posttraining.
[c] Difference between pretraining and posttraining without feedback.

internal rotation and a relative 2.3° increase in upward rotation in the video group after feedback training support the clinical significance of video feedback training.

We observed an increase (4.2%–18.1% of MVIC) in LT muscle activity and a decrease (0.56–1.17) in the UT/LT ratio in the EMG biofeedback group as compared with the video feedback group during tasks. Increased activation of the LT and decreased activation of the UT or the UT/LT ratio have been suggested to possibly correct the abnormal scapular motion.[1,14,15,18,22] Although our findings are similar to those of previous studies[15,18,22] (our finding: 4.2%–18.1% of MVIC versus previous studies: average 10.2% of MVIC), this small improvement in muscle activity did not correspond to the scapular kinematic findings in the participants with SIS.

Participants in both the video feedback and EMG biofeedback groups had displayed decreases in UT absolute muscle activity and in UT/LT and UT/SA muscle balance ratios as well as an increase in LT muscle activity. These results are similar to those of previous research.[15,20,21] Additionally, with the aid of video feedback, the participants were able to improve their scapular upward rotation and internal rotation during tasks. However, SA muscle activity did not differ between the training groups. Earlier investigators[22] examined conscious control training in patients with SIS and found increased UT/SA ratios. The authors[22,32] indicated that excessive scapular retraction would inhibit the SA activity by placing the muscle in a lengthened position, thus leading to imbalance in the scapular muscles.

Although the immediate retention effect of feedback training was supported, the decline of improvement in scapular internal rotation and UT/SA ratios indicated that further scapular-control training exercises may be needed for a long-term effect. The results of the pre- and post-without-feedback comparisons indicated improvements in both groups after training. Feedback was effective in promoting unconscious correction of the scapula. This finding is in agreement with the results of several studies.[15,18,20,21] To maintain steady improvement, further scapular-control training exercises are needed. In future work, the long-term effects of a series of scapular-control exercises should be investigated.

LIMITATIONS

The limitations of this study should be noted. First, it was not feasible to blind the assessor during the experiment. However, the main outcomes were assessed objectively by kinematic and EMG instruments, which should minimize assessor bias. Second, we used a 1-session intervention; the long-term effects and possible retention of scapular-control skills have yet to be investigated. Third, during the training sessions, the participants were instructed to concentrate on multiple external cues, including the monometer, the therapist's oral and tactile cues, and feedback from the screen. Such multitasking may have divided the attention of the participants and thus led to a decreased learning effect.

CONCLUSIONS

As compared with video feedback training, EMG biofeedback training improved muscle activity. In contrast, relative to EMG biofeedback, video feedback produced higher scapular upward rotation in participants with SIS. Both types of feedback training had positive effects: decreases in UT/LT and UT/SA muscle ratios, UT muscle activity, and scapular internal rotation. The use of EMG biofeedback in patients with SIS could yield a learning effect on muscle control, and the use of video feedback can improve the correction of scapular upward rotation.

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