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Original Article

Effect of Smartphone-Based Visual Biofeedback During Scapular Stabilization Exercises in Individuals with Subacromial Pain Syndrome

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ABSTRACT

Background: Scapular stabilization exercises are commonly used to manage subacromial pain syndrome, but inaccurate exercise performance may limit their effectiveness. Smartphone-based real-time visual feedback may improve movement awareness and exercise execution without requiring specialized equipment. Objective: To determine whether smartphone-based visual feedback added to scapular stabilization exercises improves clinical, psychological, adherence, and implementation outcomes in individuals with subacromial pain syndrome. Methods: This assessor-blinded, parallel-group randomized controlled trial included 54 participants allocated equally to an experimental group receiving smartphone-based visual feedback with conventional rehabilitation and a control group receiving the same programme without visual feedback. Treatment was delivered three times weekly for eight weeks. Outcomes were assessed at baseline, Week 4, Week 8, three months, and six months. The primary outcome was the Shoulder Pain and Disability Index. Continuous outcomes were evaluated using longitudinal mixed-effects models. Results: Forty-seven participants completed post-intervention and follow-up assessments. At Week 8, SPADI scores were 22.8 ± 8.7 in the experimental group and 31.6 ± 10.3 in the control group, with an unadjusted mean difference of −8.8 points (95% CI, −14.4 to −3.2; (p=0.003)). Significant group-by-time interactions favoured the experimental group for SPADI, pain intensity, shoulder range of motion, strength, kinesiophobia, and pain catastrophizing. The experimental group also demonstrated higher exercise adherence and satisfaction. No serious intervention-related adverse events occurred. Conclusion: Smartphone-based real-time visual feedback may enhance the effects of scapular stabilization rehabilitation on pain, disability, shoulder function, and patient engagement, although larger multicentre trials are required. Keywords: Subacromial pain syndrome; scapular stabilization; visual feedback; smartphone rehabilitation; shoulder pain; motor learning; physiotherapy.

INTRODUCTION

Shoulder pain is a common musculoskeletal complaint associated with functional limitation, work absenteeism, increased healthcare use, and reduced quality of life. Subacromial pain syndrome (SAPS) is among the most frequently diagnosed non-traumatic shoulder disorders and encompasses pain arising from the rotator cuff and surrounding subacromial structures, particularly during arm elevation and overhead activity. Contemporary evidence recognizes SAPS as a multifactorial clinical condition rather than the consequence of isolated mechanical impingement. Altered scapular movement, impaired neuromuscular control, rotator cuff dysfunction, reduced muscular capacity, pain-related movement adaptations, and psychosocial factors may interact to influence symptom persistence and disability (1).

Exercise therapy remains the principal conservative intervention for SAPS, with scapular stabilization exercises commonly incorporated to improve scapular muscle coordination, dynamic shoulder stability, and scapulohumeral control during upper-limb movement. Evidence from randomized trials and systematic reviews indicates that scapular-focused exercise can reduce pain and disability and improve shoulder function, although the magnitude of benefit and effects on range of motion vary across exercise protocols and patient populations (2–4). Progressive exercise is also central to rehabilitation across rotator cuff-related shoulder disorders, but its effectiveness depends on appropriate loading, tolerability, treatment progression, and continued patient participation (5,6). These findings suggest that clinical outcomes may be influenced not only by the exercises prescribed but also by the accuracy, consistency, and quality with which patients perform them.

Individuals with SAPS may have difficulty recognizing compensatory movement patterns during exercise, including excessive shoulder elevation, trunk lateral flexion, and poorly coordinated scapular movement. Verbal instructions and therapist demonstration can assist movement correction, but these approaches depend on the therapist's observation and the patient's interpretation of the instructions. Real-time visual feedback may provide more immediate knowledge of performance by allowing patients to observe their movement, identify errors, and make corrections while completing the exercise. Although electromyographic and laboratory-based biofeedback systems have demonstrated potential for modifying scapular muscle activation and movement performance, their cost, technical requirements, and limited portability may restrict their routine clinical use (7). A smartphone camera may offer a simpler method of providing real-time visual movement feedback without requiring specialized motion-analysis equipment.

Despite the increasing use of digital technologies in rehabilitation, evidence regarding smartphone-assisted real-time visual feedback during scapular stabilization exercises remains limited. Previous research has predominantly examined conventional scapular exercise, laboratory-based biofeedback, or short-term biomechanical outcomes, with less attention given to sustained clinical recovery, psychological responses, exercise adherence, patient satisfaction, and implementation outcomes. It therefore remains uncertain whether adding smartphone-based visual feedback to an otherwise identical scapular stabilization programme provides benefits beyond therapist demonstration and verbal feedback alone. This randomized controlled trial investigated the effects of smartphone-based real-time visual biofeedback combined with scapular stabilization exercises on shoulder pain and disability, pain intensity, shoulder range of motion, muscle strength, scapular movement quality, kinesiophobia, pain catastrophizing, perceived recovery, exercise adherence, and patient satisfaction in individuals with SAPS. It was hypothesized that participants receiving visual feedback would demonstrate greater improvements in clinical and patient-reported outcomes than participants receiving the same rehabilitation programme without visual feedback.

MATERIALS AND METHODS

This prospective, two-arm, parallel-group, assessor-blinded randomized controlled trial evaluated the effectiveness of smartphone-based real-time visual biofeedback incorporated into a standardized scapular stabilization exercise programme for individuals with SAPS. Participants were allocated in a 1:1 ratio to an experimental group receiving conventional physiotherapy, scapular stabilization exercises, and smartphone-based visual feedback or to a control group receiving the same conventional physiotherapy and exercise programme without visual feedback. Outcomes were evaluated at baseline, Week 4, Week 8, three months, and six months. The principal post-intervention comparison for the primary outcome was conducted at Week 8, immediately following completion of the supervised intervention.

The study was conducted in outpatient physiotherapy departments and affiliated rehabilitation clinics in Peshawar, Khyber Pakhtunkhwa, Pakistan. Potential participants were identified through referrals from orthopaedic consultants and physiotherapists working in the participating facilities. Individuals considered potentially eligible underwent a standardized clinical assessment by the principal investigator. Eligible individuals received verbal and written explanations of the study procedures, potential benefits, and participation requirements before providing written informed consent.

Men and women aged 18–60 years were eligible when they presented with unilateral shoulder pain of at least six weeks' duration, reported pain during arm elevation or overhead activity, and fulfilled the clinical criteria for SAPS. Clinical eligibility required at least three positive findings among the Neer test, Hawkins–Kennedy test, painful arc test, empty-can test, and external-rotation resistance test. Participants were also required to have a baseline Shoulder Pain and Disability Index score of at least 20 points and sufficient ability to understand the study

instructions and participate in the rehabilitation programme. Individuals were excluded if they had undergone previous shoulder surgery, sustained a shoulder fracture, or presented with a full-thickness rotator cuff tear, adhesive capsulitis, glenohumeral instability, previous shoulder dislocation, cervical radiculopathy, a neurological disorder affecting upper-limb function, inflammatory arthropathy, or another systemic musculoskeletal condition. Additional exclusion criteria were receipt of a corticosteroid injection during the preceding three months, current pregnancy, cognitive impairment that prevented informed participation, or concurrent participation in another rehabilitation programme for shoulder pain.

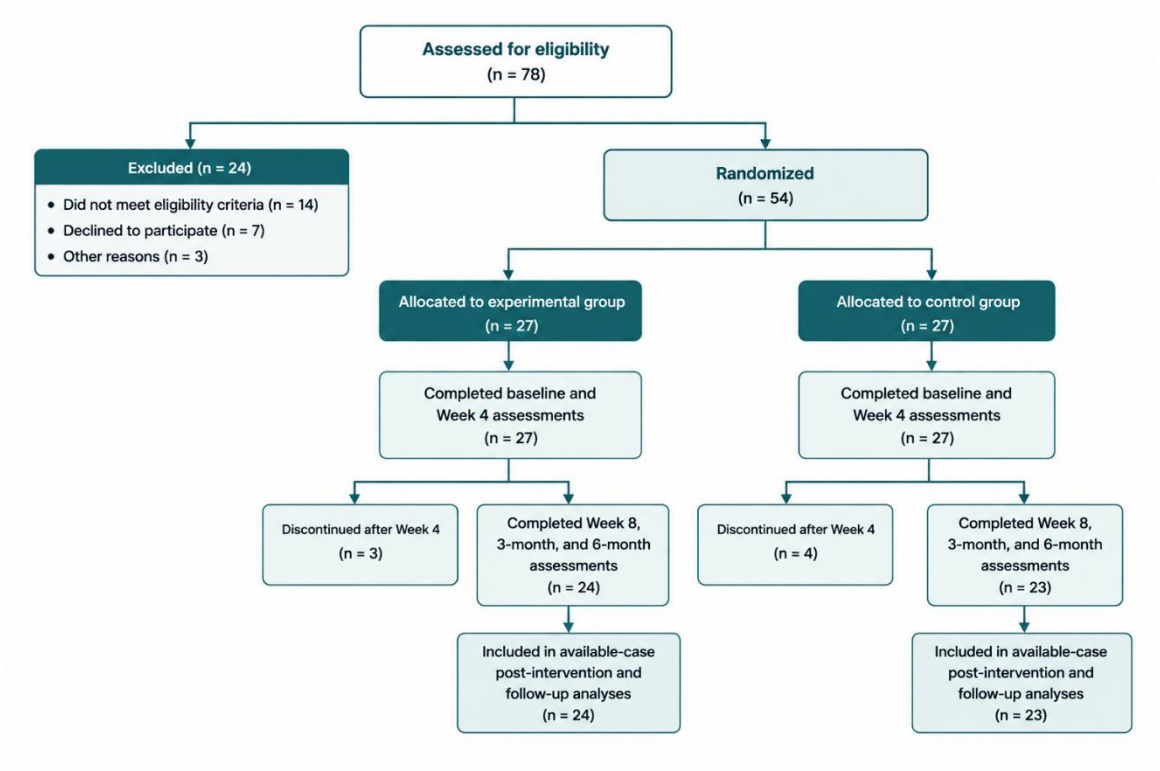

Figure 1 CONSORT Flowchart

The sample size was calculated using G*Power version 3.1 for a repeated-measures comparison involving two treatment groups and five assessment occasions. The calculation assumed a moderate effect size of (f=0.25), a two-sided alpha level of 0.05, statistical power of 80%, and a correlation of 0.50 among repeated measurements. The minimum required sample was 48 participants. To accommodate an anticipated attrition rate of approximately 10%–15%, the target sample was increased to 54 participants, with 27 participants allocated to each treatment group.

An independent researcher who was not involved in participant recruitment, treatment delivery, or outcome assessment generated the allocation sequence using a computer-based randomization procedure. Permuted block randomization with variable block sizes of four and six was used to maintain approximate balance between the groups while reducing the predictability of upcoming allocations. Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes. After completion of the baseline assessment, the treating physiotherapist opened the next envelope in sequence immediately before beginning the allocated intervention.

Blinding of participants and treating physiotherapists was not feasible because visual feedback formed an observable component of the experimental intervention. All clinical outcome assessments were therefore conducted by an independent physiotherapist who was unaware of treatment allocation. Participants were instructed not to disclose their allocation to the assessor. Group identities were also coded during statistical analysis, and the treatment codes were retained until completion of the primary analysis.

Both groups participated in an eight-week rehabilitation programme comprising three supervised sessions per week. Each treatment session lasted approximately 45–60 minutes. The common rehabilitation programme included patient education, symptom-management strategies, stretching of shortened shoulder musculature when clinically indicated, and progressive scapular stabilization exercises. Participants in both groups also received a standardized home-exercise programme. The same progression principles, treatment frequency, session duration,

and clinical criteria were applied to both groups to ensure that visual feedback was the principal difference between the interventions.

Participants allocated to the experimental group completed the scapular stabilization exercises while receiving smartphone-based real-time visual feedback. A smartphone camera was positioned posterior to the participant, and the live display was arranged so that the participant could observe scapular movement during exercise performance. Participants were instructed to use the visual display to identify and correct compensatory strategies, including excessive shoulder elevation, trunk lateral flexion, and poorly controlled scapular positioning. The treating physiotherapist simultaneously provided standardized verbal instructions and corrective cues. The programme progressed through three sequential phases, moving from scapular motor-control training to muscular endurance and strengthening and then to functional integration. Progression was permitted when the participant reported pain of no more than 3 on a 0–10 scale during exercise, demonstrated acceptable movement quality, and completed the prescribed repetitions without clinically observable compensation.

Participants allocated to the control group received the same conventional physiotherapy, scapular stabilization exercises, home programme, treatment duration, and progression criteria as the experimental group. Exercises were taught using therapist demonstration and standardized verbal feedback, but participants did not receive real-time smartphone-based visual feedback. The treating physiotherapists used the same clinical progression criteria in both groups to minimize differences in exercise dose and treatment content.

The primary outcome was shoulder pain and disability measured using the Shoulder Pain and Disability Index. The SPADI is a 13-item self-administered questionnaire comprising a five-item pain subscale and an eight-item disability subscale. Items are scored from 0 to 10, and the combined score is converted to a scale ranging from 0 to 100, with higher scores indicating greater pain and disability. The Urdu version of the SPADI has demonstrated acceptable reliability and validity for evaluating individuals with shoulder disorders (8,9).

Pain intensity was measured using the 11-point Numeric Pain Rating Scale, ranging from 0, representing no pain, to 10, representing the worst imaginable pain. The scale has demonstrated reliability, construct validity, responsiveness, and clinically interpretable change in patients with SAPS (10). Active shoulder flexion, abduction, and external rotation were measured using a digital inclinometer in standardized testing positions. Three measurements were obtained for each movement, and the mean of the three measurements was used in the analysis. Digital inclinometry has demonstrated acceptable intra-rater and inter-rater reliability for measuring shoulder mobility (11). Isometric shoulder muscle strength was evaluated using a hand-held dynamometer. Three maximal voluntary contractions were performed in standardized testing positions, and the highest recorded value was retained for analysis. Hand-held dynamometry has demonstrated acceptable validity and reliability for clinical assessment of shoulder strength (12).

Scapular movement quality was evaluated using the Scapular Dyskinesis Test during repeated bilateral arm elevation and lowering. Scapular motion was classified as normal or as demonstrating observable scapular dyskinesis according to established visual assessment criteria (13). Fear of movement was measured using the 11-item Tampa Scale for Kinesiophobia. Total scores range from 11 to 44, with higher scores indicating greater fear of movement or reinjury (14). Pain-related catastrophic thinking was evaluated using the 13-item Pain Catastrophizing Scale, which assesses rumination, magnification, and helplessness. Scores range from 0 to 52, with higher values indicating greater pain catastrophizing (15). Perceived recovery was assessed after treatment using the Global Rating of Change scale, ranging from −7, indicating a very great deterioration, to +7, indicating a very great improvement (16).

Implementation outcomes were evaluated in the experimental group following completion of the eight-week intervention. Intervention acceptability, perceived appropriateness, and feasibility were measured using the four-item Acceptability of Intervention Measure, Intervention Appropriateness Measure, and Feasibility of Intervention Measure, respectively. Each instrument uses a five-point Likert response scale, with higher scores indicating more favourable perceptions of the intervention (17). The usability of the smartphone-based feedback procedure was assessed using the 10-item System Usability Scale, which produces a total score ranging from 0 to 100, with higher scores indicating greater perceived usability (18). Home-exercise adherence was recorded using participant exercise logs and expressed as the percentage of prescribed exercises completed. Attendance at supervised sessions was documented using treatment records, and patient satisfaction was assessed at the end of the intervention using a five-point Likert scale. Any adverse symptoms or events occurring during the treatment period were recorded.

Outcome measurements were completed at baseline, Week 4, Week 8, three months, and six months by the blinded assessor using standardized procedures. The SPADI, pain intensity, shoulder range of motion, muscle strength, scapular dyskinesis, kinesiophobia, and pain catastrophizing were evaluated at the scheduled clinical assessment points. The Global Rating of Change was administered only after treatment had commenced because it required participants to compare their current condition with their pretreatment status. Implementation measures were administered only to participants who received smartphone-based visual feedback.

Before participant recruitment, the treating physiotherapists and outcome assessor received standardized training in the study procedures. A treatment manual was used to guide exercise selection, progression, therapist cueing, session content, and progression criteria. Treatment fidelity and participant engagement were documented using session-attendance records, participant exercise logs, and therapist checklists. These procedures were used to promote consistency of intervention delivery and outcome measurement across participating facilities.

Each participant was assigned a unique study identification code. Data were initially recorded on standardized case-report forms and subsequently entered into a password-protected electronic database accessible only to authorized study personnel. Data-entry accuracy was evaluated through double-entry checking and periodic review of the electronic records against the original case-report forms.

Statistical analyses were performed using IBM SPSS Statistics version 27.0. Participant characteristics and baseline measurements were summarized using descriptive statistics. Continuous variables were reported as mean and standard deviation when their distributions were approximately symmetrical and as median and interquartile range when distributional assumptions were not satisfied. Categorical variables were summarized as frequencies and percentages. Baseline characteristics were evaluated descriptively, while categorical comparisons used the chi-square test or Fisher's exact test when expected cell counts were insufficient.

The primary analysis followed the intention-to-treat principle. Continuous outcomes measured repeatedly over time were analysed using linear mixed-effects models that included treatment group, assessment time, and the group-by-time interaction as fixed effects, with participants specified as the repeated observational unit. The mixed-effects approach allowed all available repeated observations to contribute to the analysis despite incomplete follow-up measurements. A statistically significant group-by-time interaction was interpreted as evidence that the pattern of change differed between the treatment groups. When an interaction was identified, Bonferroni-adjusted post hoc contrasts were used to compare the groups at the relevant assessment points. Results were reported using model-estimated mean differences, 95% confidence intervals, and exact p-values. Standardized treatment effects were summarized using Cohen's (d), while model effects were expressed using partial eta squared where applicable. Categorical outcomes, including the proportion of participants demonstrating scapular dyskinesis, were compared using the chi-square test or Fisher's exact test, as appropriate. Implementation outcomes were summarized descriptively because they were collected only in the experimental group. A per-protocol sensitivity analysis was conducted to evaluate the robustness of the primary findings. All statistical tests were two-sided, and statistical significance was set at ($p<0.05$).

The study protocol was approved by the relevant institutional research ethics committee before participant recruitment. All participants provided written informed consent before enrolment and were informed that they could withdraw from the study without affecting their routine clinical care. Participant information was handled confidentially using coded study identifiers. The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable national research-ethics requirements.

Statistical Analysis Amendment

As a supportive analysis, unadjusted between-group contrasts at Week 8 and six months were calculated from the observed group means, standard deviations, and available-case denominators using Welch's independent-samples method. Mean differences were expressed as experimental minus control values and reported with 95% confidence intervals. Standardized between-group effects were calculated as Cohen's (d) using the pooled standard deviation. These supportive time-specific comparisons were interpreted alongside the primary longitudinal mixed-effects analyses.

RESULTS

Seventy-eight individuals were assessed for eligibility. Twenty-four were excluded, including 14 who did not satisfy the eligibility criteria, seven who declined participation, and three who were excluded for other reasons.

The remaining 54 participants were randomly allocated equally to the experimental group receiving smartphone-based real-time visual feedback and the control group receiving the same rehabilitation programme without visual feedback.

All randomized participants completed the baseline and Week 4 assessments. Seven participants discontinued participation after Week 4, including three from the experimental group and four from the control group. The reasons for discontinuation were personal commitments in three participants, inability to attend scheduled treatment sessions in two, and loss to follow-up in two. Consequently, 24 participants in the experimental group and 23 in the control group completed the Week 8, three-month, and six-month assessments. Overall attrition was 13.0%, comprising 11.1% in the experimental group and 14.8% in the control group.

Baseline Characteristics

The baseline demographic and clinical characteristics are presented in Table 2. The groups had similar distributions of age, sex, body mass index, affected shoulder, symptom duration, shoulder pain and disability, pain intensity, shoulder mobility, muscle strength, scapular dyskinesis, kinesiophobia, and pain catastrophizing. Baseline characteristics were presented descriptively because group allocation was determined by randomization.

Table 2. Baseline Demographic and Clinical Characteristics

Characteristic	Experimental Group (n=27)	Control Group (n=27)
Age, years	38.7 ± 9.2	39.4 ± 8.8
Male sex	14 (51.9)	15 (55.6)
Female sex	13 (48.1)	12 (44.4)
Body mass index, kg/m²	26.3 ± 3.4	26.8 ± 3.6
Right dominant arm	25 (92.6)	24 (88.9)
Right shoulder affected	16 (59.3)	17 (63.0)
Symptom duration, months	4.8 ± 2.1	5.1 ± 2.3
SPADI total score, 0–100	58.6 ± 11.2	59.4 ± 10.8
NPRS score, 0–10	6.7 ± 1.1	6.8 ± 1.0
Shoulder flexion, degrees	141.5 ± 14.8	139.9 ± 15.6
Shoulder abduction, degrees	133.4 ± 17.3	131.8 ± 16.5
External rotation, degrees	58.7 ± 9.1	57.9 ± 8.8
Shoulder strength, kg	12.8 ± 2.6	12.5 ± 2.7
Positive Scapular Dyskinesis Test	20 (74.1)	19 (70.4)
TSK-11 score	29.8 ± 5.2	30.3 ± 5.6
PCS score	22.4 ± 6.5	23.1 ± 6.8

Values are presented as mean ± standard deviation or n (%). SPADI, Shoulder Pain and Disability Index; NPRS, Numeric Pain Rating Scale; TSK-11, 11-item Tampa Scale for Kinesiophobia; PCS, Pain Catastrophizing Scale.

Longitudinal Clinical Outcomes

Both groups demonstrated progressive improvement in shoulder pain, disability, range of motion, muscle strength, kinesiophobia, and pain catastrophizing during treatment and follow-up. The experimental group generally demonstrated larger improvements than the control group, particularly after completion of the eight-week intervention. The observed values at each assessment are presented in Table 3.

Table 3. Primary and Secondary Outcomes Across the Assessment Period

Outcome	Group	Baseline	Week 4	Week 8	3 Months	6 Months
SPADI, 0–100	Experimental	58.6 ± 11.2	39.8 ± 10.4	22.8 ± 8.7	18.5 ± 7.9	16.4 ± 7.3
	Control	59.4 ± 10.8	45.9 ± 11.0	31.6 ± 10.3	27.6 ± 9.4	24.8 ± 8.8
NPRS, 0–10	Experimental	6.7 ± 1.1	4.1 ± 1.2	2.0 ± 1.0	1.7 ± 0.9	1.5 ± 0.8
	Control	6.8 ± 1.0	4.8 ± 1.3	3.0 ± 1.2	2.8 ± 1.1	2.5 ± 1.1
Shoulder flexion, degrees	Experimental	141.5 ± 14.8	155.8 ± 12.5	170.2 ± 8.1	172.5 ± 7.6	173.4 ± 7.3
	Control	139.9 ± 15.6	149.4 ± 13.6	161.8 ± 10.6	163.8 ± 10.0	165.0 ± 9.5
Shoulder abduction, degrees	Experimental	133.4 ± 17.3	148.2 ± 14.8	166.7 ± 9.4	168.4 ± 8.9	169.3 ± 8.6
	Control	131.8 ± 16.5	143.1 ± 15.2	156.8 ± 11.2	158.6 ± 10.5	159.7 ± 10.2
External rotation, degrees	Experimental	58.7 ± 9.1	66.8 ± 8.2	75.6 ± 6.8	77.4 ± 6.5	78.0 ± 6.2
	Control	57.9 ± 8.8	63.2 ± 8.4	69.2 ± 7.3	70.5 ± 7.1	71.4 ± 6.8
Shoulder strength, kg	Experimental	12.8 ± 2.6	15.2 ± 2.5	17.3 ± 2.3	17.8 ± 2.2	18.0 ± 2.1
	Control	12.5 ± 2.7	14.1 ± 2.5	15.3 ± 2.4	15.6 ± 2.3	15.8 ± 2.2
TSK-11 score	Experimental	29.8 ± 5.2	25.6 ± 4.9	21.8 ± 4.5	20.4 ± 4.3	19.6 ± 4.2
	Control	30.3 ± 5.6	27.8 ± 5.2	25.1 ± 4.9	24.3 ± 4.8	23.6 ± 4.6
PCS score	Experimental	22.4 ± 6.5	18.3 ± 5.8	14.6 ± 5.2	12.8 ± 4.9	11.7 ± 4.6
	Control	23.1 ± 6.8	20.5 ± 6.1	17.8 ± 5.7	16.7 ± 5.4	15.9 ± 5.2

Values are presented as mean ± standard deviation. Baseline and Week 4 values are based on 27 participants per group. Week 8, three-month, and six-month values are based on 24 experimental-group and 23 control-group participants. SPADI, Shoulder Pain and Disability Index; NPRS, Numeric Pain Rating Scale; TSK-11, 11-item Tampa Scale for Kinesiophobia; PCS, Pain Catastrophizing Scale.

The longitudinal mixed-effects analysis demonstrated a significant group-by-time interaction for SPADI scores ((p<0.001)), indicating that the pattern of improvement differed between the treatment groups. From baseline to Week 8, the mean SPADI score decreased by 35.8 points in the experimental group and by 27.8 points in the control group.

At Week 8, the observed mean SPADI score was 22.8 ± 8.7 in the experimental group and 31.6 ± 10.3 in the control group. The unadjusted between-group difference was −8.8 points (95% CI, −14.4 to −3.2; (p=0.003); Cohen's (d=-0.92)). At six months, the corresponding scores were 16.4 ± 7.3 and 24.8 ± 8.8, producing a between-group difference of −8.4 points (95% CI, −13.2 to −3.6; (p=0.001); Cohen's (d=-1.04)). These findings indicate that the larger reduction in shoulder pain and disability observed in the experimental group was maintained during follow-up.Significant group-by-time interactions were identified for pain intensity ((p=0.002)), shoulder flexion ((p=0.012)), shoulder abduction ((p=0.018)), external rotation ((p=0.027)), shoulder strength ((p=0.004)), kinesiophobia ((p=0.011)), and pain catastrophizing ((p=0.017)). The experimental group demonstrated larger improvements across these outcomes than the control group.

At Week 8, pain intensity was 1.0 point lower in the experimental group (95% CI, −1.7 to −0.3; (p=0.003); (d=-0.91)). Shoulder flexion was 8.4 degrees greater (95% CI, 2.8 to 14.0; (p=0.004); (d=0.89)), abduction was 9.9 degrees greater (95% CI, 3.8 to 16.0; (p=0.002); (d=0.96)), and external rotation was 6.4 degrees greater (95% CI, 2.2 to 10.6; (p=0.003); (d=0.91)). Shoulder strength was 2.0 kg greater in the experimental group (95% CI, 0.6 to 3.4; (p=0.006); (d=0.85)).

The experimental group also had a 3.3-point lower TSK-11 score at Week 8 (95% CI, −6.1 to −0.5; (p=0.021); (d=-0.70)). The corresponding PCS difference was −3.2 points (95% CI, −6.4 to 0.0; (p=0.051); (d=-0.59)). Although the time-specific PCS contrast at Week 8 narrowly crossed the null value, the longitudinal analysis indicated that the overall pattern of change differed between the groups. By six months, the between-group PCS difference was −4.2 points (95% CI, −7.1 to −1.3; (p=0.005); (d=-0.86)).

Table 4. Longitudinal Interaction Results and Time-Specific Between-Group Contrasts

Outcome	Group × Time p-value	Week 8 Mean Difference (95% CI)	Week 8 p-value	Week 8 Cohen's d	6-Month Mean Difference (95% CI)	6-Month p-value	6-Month Cohen's d
SPADI, points	<0.001	−8.8 (−14.4 to −3.2)	0.003	−0.92	−8.4 (−13.2 to −3.6)	0.001	−1.04
NPRS, points	0.002	−1.0 (−1.7 to −0.3)	0.003	−0.91	−1.0 (−1.6 to −0.4)	0.001	−1.04
Shoulder flexion, degrees	0.012	8.4 (2.8 to 14.0)	0.004	0.89	8.4 (3.4 to 13.4)	0.002	0.99
Shoulder abduction, degrees	0.018	9.9 (3.8 to 16.0)	0.002	0.96	9.6 (4.0 to 15.2)	0.001	1.02
External rotation, degrees	0.027	6.4 (2.2 to 10.6)	0.003	0.91	6.6 (2.8 to 10.4)	0.001	1.02
Shoulder strength, kg	0.004	2.0 (0.6 to 3.4)	0.006	0.85	2.2 (0.9 to 3.5)	0.001	1.02
TSK-11, points	0.011	−3.3 (−6.1 to −0.5)	0.021	−0.70	−4.0 (−6.6 to −1.4)	0.003	−0.91
PCS, points	0.017	−3.2 (−6.4 to 0.0)	0.051	−0.59	−4.2 (−7.1 to −1.3)	0.005	−0.86

Mean differences were calculated as experimental minus control values. Negative values favour the experimental group for SPADI, NPRS, TSK-11, and PCS; positive values favour the experimental group for range of motion and strength. Group-by-time p-values are from the longitudinal mixed-effects analyses. Time-specific estimates were calculated from the reported means, standard deviations, and available-case denominators using Welch's method. Cohen's (d) was calculated using the pooled standard deviation.

At Week 8, normal scapular movement was observed in 19 of 24 participants in the experimental group (79.2%) and 13 of 23 participants in the control group (56.5%). The between-group difference did not reach statistical significance using the Pearson chi-square test ((\chi^2=2.77), (p=0.096)).

Home-exercise adherence was consistently higher in the experimental group. At Week 4, adherence was 88.6 ± 9.8% in the experimental group and 80.4 ± 10.9% in the control group, corresponding to an unadjusted difference of 8.2 percentage points (95% CI, 2.5 to 13.9; (p=0.005); (d=0.79)). At Week 8, adherence was 91.4 ± 8.2% and 82.6 ± 10.5%, respectively, with a difference of 8.8 percentage points (95% CI, 3.2 to 14.4; (p=0.003); (d=0.94)).

Treatment satisfaction at Week 8 was 4.7 ± 0.5 in the experimental group and 4.2 ± 0.7 in the control group. The unadjusted difference was 0.5 points (95% CI, 0.1 to 0.9; (p=0.008); (d=0.83)). Participants receiving smartphone-

based visual feedback also reported high intervention acceptability, appropriateness, feasibility, and usability. No serious intervention-related adverse events occurred. Two participants experienced transient post-exercise muscle soreness during the first treatment week, which resolved without treatment modification.

Table 5. Adherence, Satisfaction, Implementation, and Safety Outcomes

Measure	Experimental Group	Control Group	Overall
Home-exercise adherence at Week 4, %	88.6 ± 9.8	80.4 ± 10.9	
Home-exercise adherence at Week 8, %	91.4 ± 8.2	82.6 ± 10.5	
Treatment satisfaction at Week 8, 1–5	4.7 ± 0.5	4.2 ± 0.7	
Acceptability of Intervention Measure, 1–5	4.68 ± 0.39		
Intervention Appropriateness Measure, 1–5	4.60 ± 0.42		
Feasibility of Intervention Measure, 1–5	4.55 ± 0.47		
System Usability Scale, 0–100	86.8 ± 6.5		
Supervised-session attendance, %	>93		
Participants with transient muscle soreness			2
Serious intervention-related adverse events			0

Values are presented as mean ± standard deviation unless otherwise indicated. Acceptability, appropriateness, feasibility, and usability were assessed only in the experimental group. The direction of the difference favoured the experimental intervention, but the available sample did not provide sufficiently precise evidence of a between-group difference in the categorical scapular-movement outcome.

DISCUSSION

This randomized controlled trial examined whether adding smartphone-based real-time visual feedback to a standardized scapular stabilization programme improved outcomes in individuals with subacromial pain syndrome. Both groups improved during treatment and follow-up, but the experimental group demonstrated greater reductions in shoulder pain and disability and pain intensity, together with larger gains in shoulder range of motion and muscle strength. The experimental group also showed greater improvement in kinesiophobia, higher exercise adherence, and greater treatment satisfaction. The categorical difference in normal scapular movement favoured the experimental group but was not statistically significant, while the Week 8 time-specific difference in pain catastrophizing was imprecise despite a significant longitudinal interaction.

The principal finding was the greater reduction in SPADI scores among participants receiving smartphone-based visual feedback. At Week 8, the experimental group had an observed SPADI score 8.8 points lower than the control group, with a large standardized effect. A similar difference remained at six months, suggesting that the additional improvement was not confined to the supervised treatment period. The magnitude of the Week 8 difference was comparable to published thresholds for clinically important SPADI change in individuals with SAPS, although such thresholds are principally intended to interpret individual change and should not substitute for a formal responder analysis (10). The findings therefore support a potentially meaningful additional benefit while avoiding the assumption that every participant achieved a clinically important response.

The results are consistent with evidence supporting scapular-focused rehabilitation for SAPS. A systematic review and meta-analysis concluded that scapular stabilization exercises improve pain and disability compared with conventional physiotherapy, although effects on shoulder mobility have varied across trials (2). Yuksel and Yesilyaprak similarly reported that adding scapular stabilization training improved pain, function, strength, and observable scapular dyskinesis in individuals with SAPS (4). Contemporary rehabilitation perspectives also emphasize that scapular dyskinesis should be interpreted within a broader clinical context that includes motor control, pain-related adaptations, muscle performance, and functional movement rather than as an isolated structural abnormality (3). The present findings extend this evidence by suggesting that the way in which exercises are performed may influence their clinical effect. Both treatment groups completed the same broad rehabilitation programme, whereas the experimental group additionally received continuous visual information during exercise performance.

Real-time visual feedback may enhance rehabilitation by providing immediate knowledge of performance. Participants can observe compensatory movement, compare their performance with the intended movement pattern, and make corrections while an exercise is being completed. This may support attention to movement quality and increase consistency of exercise execution. Evidence from electromyographic biofeedback research suggests that feedback can modify scapular muscle recruitment, while motor-control retraining studies have reported improvements in pain, strength, proprioception, shoulder function, and movement performance when feedback is incorporated into treatment (7,19). These findings are compatible with the broader role of biofeedback in improving movement awareness and facilitating more targeted neuromuscular retraining. Nevertheless, the present study did not directly measure muscle activation, proprioception, three-dimensional scapular kinematics, or motor-learning retention. Improved neuromuscular control therefore remains a plausible explanation rather than a demonstrated physiological mechanism.

Greater gains in shoulder flexion, abduction, external rotation, and strength were observed in the experimental group. These outcomes may reflect improved tolerance of arm elevation, reduced pain-related guarding, greater exercise engagement, or more consistent execution of the stabilization programme. Appropriate scapular contribution is relevant to efficient upper-limb movement, but scapular dyskinesis should not be interpreted as an isolated structural cause of SAPS. Current evidence instead considers it a potentially modifiable movement impairment that may be associated with pain, muscle fatigue, altered motor control, and compensatory movement strategies (3). In the current study, the proportion with normal scapular movement was higher in the experimental group, but the corrected between-group comparison was not statistically significant. The intervention should therefore be interpreted as a strategy for facilitating movement awareness and exercise performance rather than as a proven method for normalizing scapular biomechanics.

The reduction in kinesiophobia provides additional evidence that visual feedback may influence more than physical performance. Observing successful and tolerable movement may increase confidence and reduce uncertainty about using the painful shoulder. Fear of movement and pain catastrophizing can contribute to activity restriction, protective movement behaviour, reduced exercise participation, and persistent musculoskeletal disability (14,15). Therapeutic education and psychologically informed interventions can reduce fear, catastrophizing, pain, and disability when integrated with active musculoskeletal rehabilitation (20,21). The PCS findings were less uniform than the TSK-11 findings: the longitudinal trajectory differed between groups, but the Week 8 contrast narrowly included the null value. This distinction should be retained because it indicates that the psychological effects were not equally strong across all measures and assessment points.

Exercise adherence was higher among participants who received visual feedback. This may have contributed to the larger clinical improvements, although the study was not designed to establish adherence as a mediator. Visual feedback may have made the exercises more interactive, increased perceived competence, or provided a clearer indication of progress. Adherence to exercise-based rehabilitation is influenced by treatment beliefs, perceived usefulness, confidence, symptom response, accessibility, clinician support, and active patient participation (25). Because adherence was measured using participant exercise logs, some degree of self-report and social-desirability bias remains possible.

The implementation findings indicate that participants considered the intervention acceptable, appropriate, feasible, and usable. The instruments used to measure these constructs have demonstrated acceptable psychometric properties for evaluating implementation outcomes (17), while the System Usability Scale is widely used to assess perceived usability of health and educational technologies (18). These findings are relevant because many digital rehabilitation interventions depend on specialized equipment, software, or immersive systems that may be difficult to introduce in routine clinical environments. Systematic reviews have reported favourable effects of digitally supported and virtual-reality-assisted rehabilitation on pain, disability, function, and self-efficacy across musculoskeletal

conditions (22–24). The present intervention used a standard smartphone rather than a proprietary platform or immersive system, but its apparent simplicity should not be equated automatically with proven scalability. Implementation outcomes were measured only in the experimental group, and the study did not quantify equipment costs, clinician time, digital literacy, technical failures, or unsupervised home use.

The study had several strengths. The randomized, parallel-group design reduced the risk of systematic allocation differences, outcome assessments were conducted by a blinded assessor, and both groups received comparable rehabilitation content and treatment duration. The inclusion of clinical, functional, psychological, adherence, implementation, and safety outcomes provided a broader assessment than pain and disability alone. Repeated evaluations through six months also permitted examination of whether observed differences persisted after the supervised intervention. The use of validated measures for shoulder pain and disability, pain intensity, shoulder mobility, strength, kinesiophobia, pain catastrophizing, perceived recovery, implementation, and usability further strengthened outcome assessment (8–18).

Several limitations should be considered. The sample was relatively small and recruited from rehabilitation facilities within one geographical region, limiting statistical precision and generalizability. Participants and treating physiotherapists could not be blinded, making expectation, attention, and performance effects possible. The actual duration of therapist contact and feedback exposure was not compared between groups. Scapular movement was classified by visual observation rather than instrumented biomechanical analysis, and although the Scapular Dyskinesis Test is clinically applicable, visual classification remains less precise than three-dimensional motion analysis or electromyography (13). Multiple outcomes and assessment points increased the possibility of chance findings, particularly for secondary outcomes. Follow-up descriptive values were based on participants with available observations, and implementation measures were collected only in the experimental group. Adherence was self-reported, and the study did not establish whether improved adherence mediated the observed clinical effects. Larger multicentre trials with prospectively specified primary endpoints, complete trial registration, objective fidelity measures, and instrumented movement assessment are required to confirm the findings.

CONCLUSION

Adding smartphone-based real-time visual feedback to a standardized scapular stabilization programme was associated with greater improvements in shoulder pain and disability, pain intensity, shoulder mobility, muscle strength, kinesiophobia, exercise adherence, and treatment satisfaction than the same rehabilitation programme without visual feedback. The differences in SPADI and several secondary outcomes persisted at six months, while evidence for improved categorical scapular movement and short-term pain catastrophizing was less conclusive. Smartphone-assisted visual feedback may represent a practical adjunct to supervised rehabilitation for subacromial pain syndrome, but larger multicentre trials with objective movement assessment and comprehensive implementation evaluation are needed before broad clinical adoption.

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