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Original Article

Evaluating A Novel AI-Driven Motion Feedback System for Improving Scapular Kinematics in Patients with Shoulder Impingement

Muhammad Asif[1], Muhammad Riaz Baig Chughtai[1], Muhammad Atif Khan[1], Abdul Rashad[1]

[1] Department of Rehabilitation & Health Sciences, Nazeer Hussain University, Karachi, Pakistan

***Corresponding author: Muhammad Asif, m.asif@nhu.edu.pk**

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ABSTRACT

Background: Shoulder impingement syndrome is frequently associated with altered scapular kinematics, pain, and functional limitation. Standard physiotherapy can improve symptoms, but accurate performance of corrective scapular movements may be limited by patients' ability to perceive and modify faulty movement patterns. Objective: To determine whether AI-driven real-time visual motion feedback added to standard physiotherapy improves scapular upward rotation, pain, and shoulder-related disability more than standard physiotherapy alone in patients with shoulder impingement syndrome. Methods: This randomized controlled trial enrolled 60 adults aged 25–60 years with clinically diagnosed shoulder impingement syndrome and observable scapular dyskinesis. Participants were allocated equally to an experimental group receiving standard physiotherapy plus AI-driven real-time visual feedback or a control group receiving standard physiotherapy alone. Both groups completed supervised sessions three times weekly for four weeks. Outcomes were assessed at baseline and post-intervention using the Visual Analog Scale, Shoulder Pain and Disability Index, and digital inclinometer measurement of scapular upward rotation. Results: All participants completed follow-up. VAS improved from 6.8 ± 1.1 to 2.9 ± 0.9 in the experimental group and from 6.6 ± 1.2 to 4.5 ± 1.0 in the control group. SPADI improved from 62.4 ± 8.5 to 28.6 ± 6.9 and from 60.9 ± 9.1 to 42.3 ± 7.8, respectively. Scapular upward rotation improved more in the experimental group, increasing from 38.2 ± 5.4° to 50.6 ± 4.8° compared with 39.1 ± 5.7° to 44.3 ± 5.2° in the control group. Conclusion: AI-driven real-time visual feedback added to standard physiotherapy produced greater short-term improvements in pain, disability, and scapular upward rotation than standard physiotherapy alone. Keywords: Artificial Intelligence, Rehabilitation, Scapula, Shoulder Impingement Syndrome, Shoulder Pain, Treatment Outcome, Visual Feedback

INTRODUCTION

Shoulder impingement syndrome is a common musculoskeletal condition associated with pain, restricted shoulder function, and difficulty performing occupational, domestic, and overhead activities. Although the condition has traditionally been explained through localized subacromial compression, contemporary rehabilitation models emphasize that altered scapular kinematics contribute substantially to symptom persistence and functional limitation. In particular, reduced scapular upward rotation, excessive anterior tilting, and altered scapulothoracic coordination may narrow the subacromial space during arm elevation, increase mechanical stress on periarticular tissues, and impair efficient shoulder movement. This biomechanical perspective has shifted rehabilitation priorities from symptom control alone toward correction of movement dysfunction and restoration of coordinated scapular control (1).

Standard physiotherapy for shoulder impingement commonly includes scapular stabilization exercises, rotator cuff strengthening, postural correction, stretching of tight anterior shoulder structures, and motor-control retraining. These interventions are clinically relevant because they target muscular imbalance and faulty movement patterns that may contribute to pain and disability. However, their effectiveness depends not only on prescription of appropriate exercises but also on the patient's ability to recognize, reproduce, and maintain correct scapular positioning during dynamic movement. In routine practice, therapist feedback is usually intermittent and clinic-dependent, while patients may struggle to identify subtle compensatory patterns during unsupervised performance. This gap between clinical instruction and accurate execution can limit motor learning, reduce exercise fidelity, and delay functional recovery (2, 3).

Feedback-based rehabilitation has therefore gained attention as a strategy to improve movement accuracy and reinforce corrective motor patterns. Visual feedback is particularly useful because it converts otherwise difficult-to-perceive biomechanical deviations into observable information that patients can use immediately during exercise. By providing external cues about movement quality, feedback systems may support error recognition, enhance active correction, and improve adherence to prescribed movement targets. Traditional feedback approaches such as mirrors, therapist observation, or basic motion tracking may be helpful, but they are limited by subjectivity, restricted precision, and reduced ability to detect complex scapular deviations across multiple planes of motion (4–6).

Artificial intelligence–assisted motion feedback systems may address some of these limitations by processing movement information in real time and providing individualized corrective cues during therapeutic exercise. In the context of shoulder rehabilitation, such systems may help patients identify insufficient scapular upward rotation, excessive anterior tilt, or poorly coordinated scapular movement while performing task-specific exercises. This approach is clinically relevant because scapular dyskinesis is not only a biomechanical abnormality but also a modifiable rehabilitation target. If real-time feedback improves movement accuracy during exercise, it may contribute to greater pain reduction and functional improvement than standard physiotherapy alone (7–10).

Despite increasing interest in digital and AI-assisted rehabilitation technologies, empirical evidence remains limited regarding their clinical value in patients with shoulder impingement syndrome. Existing literature supports the importance of scapular-focused rehabilitation and feedback-enhanced motor training, but fewer controlled trials have examined whether AI-driven real-time visual feedback provides measurable additional benefit when integrated with conventional physiotherapy. In particular, there is limited evidence comparing standard rehabilitation alone with standard rehabilitation supplemented by AI-assisted feedback using patient-centered outcomes such as pain intensity and shoulder-related disability together with biomechanical outcomes such as scapular upward rotation (11–13).

The present randomized controlled trial was designed to address this gap by evaluating whether an AI-driven real-time visual motion feedback system, when added to standard physiotherapy, produces superior improvements in scapular kinematics, pain, and functional status among adults with clinically diagnosed shoulder impingement syndrome. The study was structured around the clinical question of whether patients receiving AI-assisted feedback in addition to standard physiotherapy would demonstrate greater improvement in scapular upward rotation, lower Visual Analog Scale scores, and reduced Shoulder Pain and Disability Index scores after four weeks of intervention compared with patients receiving standard physiotherapy alone (14).

MATERIAL AND METHODS

A randomized controlled trial was conducted over a four-month period in outpatient physiotherapy settings within the Industrial and Urban Core region of Punjab. Patients presenting with shoulder pain were screened consecutively for eligibility. Adults aged 25–60 years were considered eligible when they

had clinically diagnosed shoulder impingement syndrome, symptoms persisting for at least six weeks, positive Neer and Hawkins-Kennedy impingement tests, and observable scapular dyskinesis during clinical assessment. Patients were excluded if they had a history of shoulder surgery, cervical radiculopathy, systemic inflammatory disease, neurological impairment, or corticosteroid injection during the preceding three months.

A total of 72 patients were screened, of whom 60 met the eligibility criteria and were enrolled. Participants were assigned in a 1:1 ratio to either the experimental group or the control group using a computer-generated randomization sequence, resulting in 30 participants in each group. Baseline demographic and clinical information was recorded before the intervention, including age, sex, duration of symptoms, pain intensity, shoulder pain-related disability, and scapular kinematic assessment. The intervention period lasted four weeks, and both groups received supervised physiotherapy sessions three times per week, with each session lasting approximately 40 minutes. Outcomes were measured at baseline and immediately after completion of the four-week intervention period.

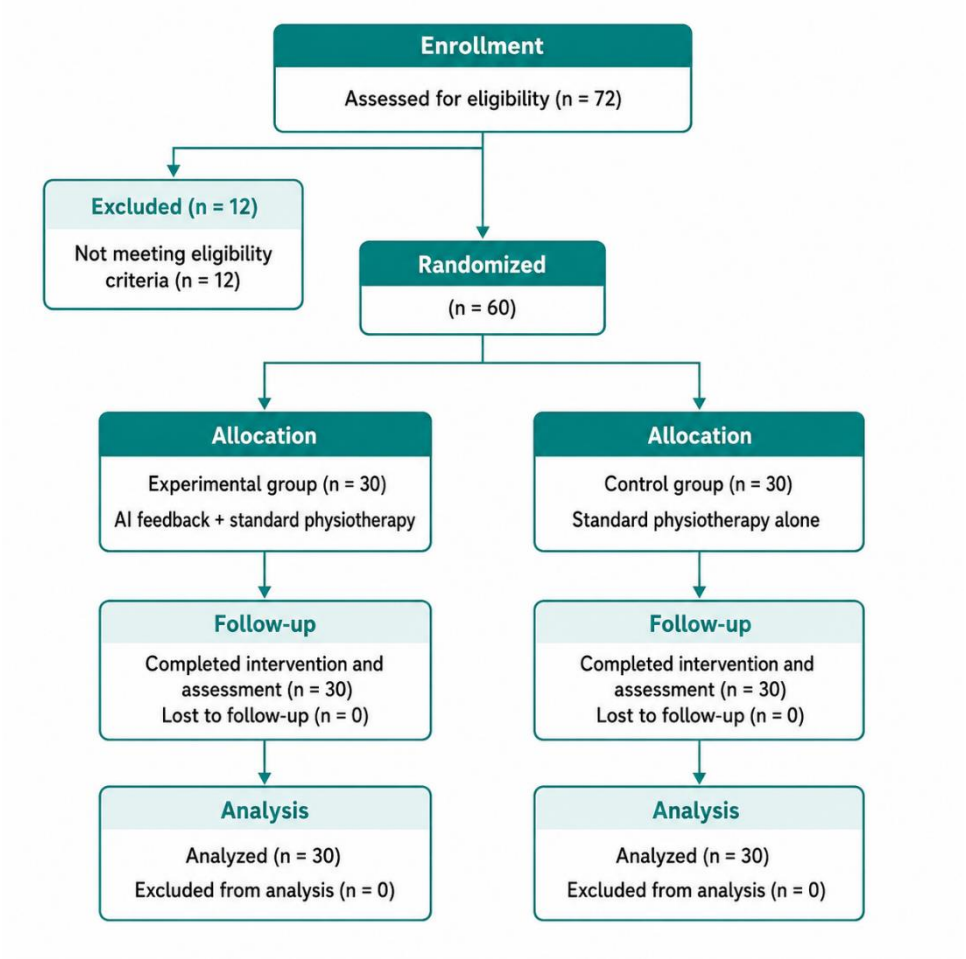

Figure 1 CONSORT Flowchart

The control group received standard physiotherapy directed at the biomechanical and functional impairments commonly associated with shoulder impingement syndrome. The intervention included scapular stabilization exercises, rotator cuff strengthening, postural correction, and stretching of tight anterior shoulder structures. Exercises were delivered under therapist supervision and focused on improving scapular control, shoulder muscle performance, and movement quality during functional arm elevation. The experimental group received the same standard physiotherapy protocol with the addition of AI-driven real-time visual motion feedback. During the feedback-assisted exercises, participants performed therapeutic movements while using a wearable sensor-based motion tracking system connected to a display interface. The system provided real-time visual cues regarding scapular positioning and movement deviations, particularly insufficient scapular upward rotation and excessive

anterior tilt during dynamic tasks. Participants were guided to correct movement errors during exercise performance based on the displayed feedback while continuing the same core rehabilitation components provided to the control group.

Pain intensity was measured using the Visual Analog Scale, with lower scores indicating lower pain intensity. Functional status was assessed using the Shoulder Pain and Disability Index, with lower scores indicating lower shoulder-related pain and disability. Scapular kinematics were assessed using a digital inclinometer, with the primary kinematic outcome reported as scapular upward rotation angle in degrees. Observational assessment of scapular dyskinesis was used during eligibility screening to confirm the presence of altered scapular movement. Outcome assessments were completed at baseline and post-intervention, allowing comparison of within-group change and between-group post-intervention differences.

The primary clinical outcomes were pain intensity and shoulder-related disability, measured by VAS and SPADI, while the principal biomechanical outcome was scapular upward rotation angle. Demographic and baseline variables were summarized using descriptive statistics. Continuous variables were expressed as mean ± standard deviation, and categorical variables were reported as frequencies and percentages. Data distribution was assessed using the Shapiro-Wilk test before inferential analysis. Within-group pre- to post-intervention differences were analyzed using paired t-tests, while between-group comparisons were performed using independent t-tests. Correlation analysis was used to examine the relationship between improvement in scapular kinematics and reduction in pain scores. Statistical significance was set at $p < 0.05$. All enrolled participants completed the intervention and post-intervention assessment, so the final analysis included all 60 randomized participants.

RESULTS

A total of 72 patients with shoulder pain were screened for eligibility, of whom 60 met the inclusion criteria and were enrolled in the trial. Participants were randomly allocated equally to the experimental group receiving standard physiotherapy plus AI-driven real-time visual motion feedback and the control group receiving standard physiotherapy alone. All randomized participants completed the four-week intervention and post-intervention assessment, resulting in complete outcome data for analysis.

Table 1. Participant Flow and Total Baseline Characteristics

Variable	Total Sample
Screened, n	72
Randomized, n	60
Experimental group, n (%)	30 (50.0)
Control group, n (%)	30 (50.0)
Completed post-intervention assessment, n (%)	60 (100.0)
Age, years, Mean ± SD	41.2 ± 8.6
Male, n (%)	34 (56.7)
Female, n (%)	26 (43.3)
Duration of symptoms, weeks, Mean ± SD	9.4 ± 2.7
Baseline VAS, Mean ± SD	6.7 ± 1.1
Baseline SPADI, Mean ± SD	61.6 ± 8.8

VAS: Visual Analog Scale; SPADI: Shoulder Pain and Disability Index; SD: standard deviation.

The enrolled sample consisted of 60 participants, with equal allocation to the experimental and control groups. The overall mean age was 41.2 ± 8.6 years, and males represented 56.7% of the sample. Mean symptom duration was 9.4 ± 2.7 weeks, indicating that participants had persistent shoulder symptoms before intervention. Complete follow-up was achieved for all randomized participants.

Baseline pain, disability, and scapular upward rotation values were similar between groups. The experimental group had a baseline VAS score of 6.8 ± 1.1 compared with 6.6 ± 1.2 in the control group, with a mean difference of 0.2. Baseline SPADI scores were 62.4 ± 8.5 and 60.9 ± 9.1, respectively. Baseline

scapular upward rotation was also comparable, with values of 38.2 ± 5.4 degrees in the experimental group and 39.1 ± 5.7 degrees in the control group.

Table 2. Baseline Outcome Comparability Between Groups

Outcome	Experimental, Mean ± SD	Control, Mean ± SD	Mean Difference	95% CI	p-value
VAS	6.8 ± 1.1	6.6 ± 1.2	0.2	-0.39 to 0.79	0.50
SPADI	62.4 ± 8.5	60.9 ± 9.1	1.5	-3.05 to 6.05	0.51
Scapular upward rotation, degrees	38.2 ± 5.4	39.1 ± 5.7	-0.9	-3.77 to 1.97	0.53

VAS: Visual Analog Scale; SPADI: Shoulder Pain and Disability Index; CI: confidence interval; SD: standard deviation. Mean differences were calculated as experimental minus control.

Table 3. Within-Group Pre- and Post-Intervention Outcomes

Outcome	Group	Pre-Intervention, Mean ± SD	Post-Intervention, Mean ± SD	Mean Change	p-value
VAS	Experimental	6.8 ± 1.1	2.9 ± 0.9	-3.9	<0.001
VAS	Control	6.6 ± 1.2	4.5 ± 1.0	-2.1	<0.001
SPADI	Experimental	62.4 ± 8.5	28.6 ± 6.9	-33.8	<0.001
SPADI	Control	60.9 ± 9.1	42.3 ± 7.8	-18.6	<0.001
Scapular upward rotation, degrees	Experimental	38.2 ± 5.4	50.6 ± 4.8	12.4	<0.001
Scapular upward rotation, degrees	Control	39.1 ± 5.7	44.3 ± 5.2	5.2	0.041

VAS: Visual Analog Scale; SPADI: Shoulder Pain and Disability Index; SD: standard deviation.

Both groups improved after four weeks of intervention, but the magnitude of improvement was greater in the experimental group. VAS decreased by 3.9 points in the experimental group compared with 2.1 points in the control group. SPADI decreased by 33.8 points in the experimental group compared with 18.6 points in the control group. Scapular upward rotation increased by 12.4 degrees in the experimental group and by 5.2 degrees in the control group, indicating a larger biomechanical improvement with AI-assisted feedback.

Table 4. Between-Group Post-Intervention Outcome Comparison

Outcome	Experimental, Mean ± SD	Control, Mean ± SD	Mean Difference	95% CI	Cohen's d	p-value
VAS	2.9 ± 0.9	4.5 ± 1.0	-1.6	-2.09 to -1.11	-1.68	<0.001
SPADI	28.6 ± 6.9	42.3 ± 7.8	-13.7	-17.51 to -9.90	-1.86	<0.001
Scapular upward rotation, degrees	50.6 ± 4.8	44.3 ± 5.2	6.3	3.72 to 8.88	1.26	0.002

VAS: Visual Analog Scale; SPADI: Shoulder Pain and Disability Index; CI: confidence interval; SD: standard deviation. Mean differences were calculated as experimental minus control.

Post-intervention comparisons favored the experimental group across all measured outcomes. The experimental group had a 1.6-point lower VAS score than the control group, with a 95% CI from -2.09 to -1.11. SPADI was 13.7 points lower in the experimental group, with a 95% CI from -17.51 to -9.90. Scapular upward rotation was 6.3 degrees higher in the experimental group, with a 95% CI from 3.72 to 8.88. The effect sizes were large for pain, disability, and scapular upward rotation, indicating a substantial post-intervention difference between treatment approaches.

Table 5. Correlation Between Scapular Kinematic Improvement and Pain Reduction

Variables	n	r	p-value
Scapular kinematic improvement and pain-score reduction	60	0.58	<0.01

r: correlation coefficient.

Correlation analysis showed a moderate positive association between improvement in scapular kinematics and reduction in pain scores. The reported correlation coefficient was 0.58, indicating that greater improvement in scapular movement was associated with greater reduction in pain intensity across the study sample.

The available results support the added benefit of AI-driven real-time visual feedback when combined with standard physiotherapy. Compared with standard physiotherapy alone, the experimental intervention produced larger improvements in pain intensity, shoulder-related disability, and scapular upward rotation after four weeks. The strongest between-group differences were observed for SPADI and VAS, while the kinematic findings suggest that improved scapular upward rotation may have contributed to better clinical outcomes.

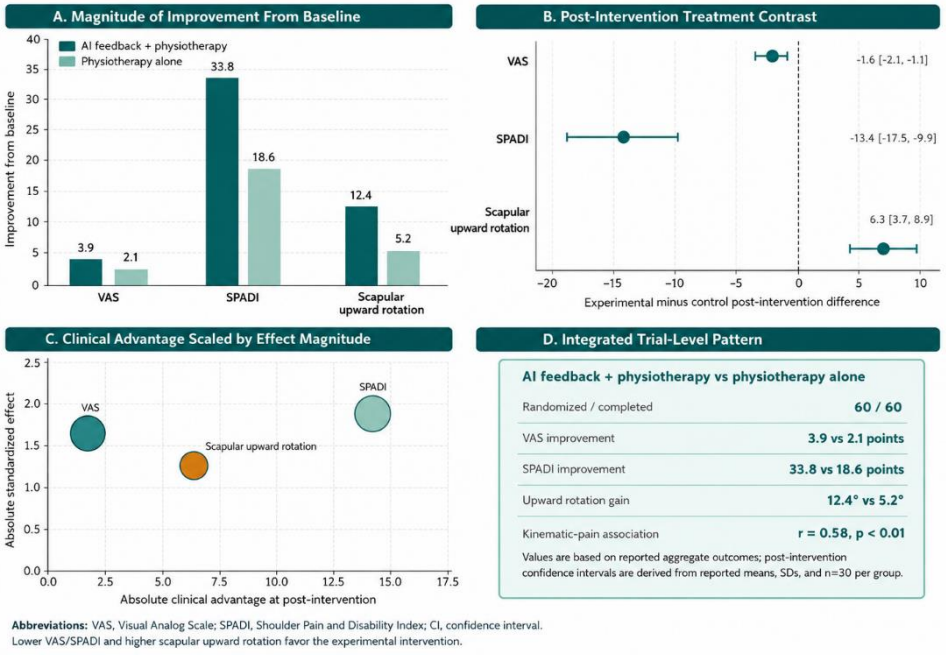

Figure 2 The panelled figure shows a consistent response gradient favoring AI-driven feedback plus physiotherapy over physiotherapy alone. Pain improved by 3.9 VAS points in the experimental group compared with 2.1 points in the control group, while SPADI improved by 33.8 points versus 18.6 points. Scapular upward rotation increased by 12.4° in the experimental group compared with 5.2° in the control group. Post-intervention treatment contrasts also favored the experimental group, with lower VAS scores, lower SPADI scores, and higher scapular upward rotation. The reported correlation between scapular kinematic improvement and pain reduction was r = 0.58, p < 0.01, supporting a clinically relevant association between biomechanical correction and symptom improvement.

DISCUSSION

The present randomized controlled trial demonstrated that adding AI-driven real-time visual motion feedback to standard physiotherapy produced greater improvements in pain intensity, shoulder-related disability, and scapular upward rotation than standard physiotherapy alone in adults with shoulder impingement syndrome. Although both groups improved after four weeks of supervised rehabilitation, the experimental group showed a larger reduction in VAS score, greater improvement in SPADI score, and a larger gain in scapular upward rotation. These findings suggest that feedback-assisted movement correction may enhance the clinical effects of conventional scapular and rotator cuff rehabilitation when the therapeutic target is not only strengthening but also restoration of coordinated scapulothoracic movement.

The superior pain reduction observed in the AI-feedback group is biomechanically plausible because altered scapular motion can increase mechanical loading within the subacromial region and perpetuate painful movement patterns. In this trial, the experimental group showed a larger improvement in scapular upward rotation, and the reported correlation between kinematic improvement and pain reduction indicated a moderate positive association between biomechanical correction and symptom relief. This pattern supports the clinical rationale that improving scapular mechanics may contribute to pain reduction in shoulder impingement, although the correlation should not be interpreted as proof of causality. The findings are consistent with previous rehabilitation literature emphasizing the value of

technology-assisted therapy, virtual or digital feedback systems, and scapular-focused interventions for improving shoulder function in subacromial pain or impingement-related disorders (15–17).

Functional improvement followed a similar pattern, with the experimental group demonstrating a larger reduction in SPADI score than the control group. This suggests that the benefit of real-time visual feedback was not limited to an isolated biomechanical measure but was also reflected in patient-reported shoulder pain and disability. The likely explanation is that visual feedback may improve exercise fidelity by helping patients recognize and correct faulty scapular positioning during active movement. In conventional physiotherapy, corrective feedback is usually dependent on therapist observation and may be intermittent, whereas a real-time motion feedback system can provide immediate external cues during each movement attempt. This continuous error-recognition and correction process may support more accurate motor performance during rehabilitation exercises (18, 19).

The improvement in scapular upward rotation is particularly important because scapular dyskinesis is a modifiable contributor to shoulder impingement symptoms. Standard physiotherapy can improve scapular control through stabilization, strengthening, and postural correction; however, patients may not always perceive subtle compensatory patterns during arm elevation. The addition of real-time visual feedback may therefore bridge the gap between therapist instruction and patient execution. In this study, the experimental group improved scapular upward rotation by 12.4 degrees compared with 5.2 degrees in the control group, indicating a larger biomechanical response when AI-assisted feedback was incorporated into rehabilitation. This supports the concept that technology-enhanced feedback may be clinically useful when the outcome depends on precise movement retraining rather than exercise completion alone (20, 21).

The findings also contribute to the emerging literature on digital and AI-assisted rehabilitation for musculoskeletal disorders. Previous reviews have described the potential value of wearable systems, exergaming, remote monitoring, and health-enabling technologies in shoulder rehabilitation, but clinical evidence remains heterogeneous and often limited by differences in devices, intervention protocols, and outcome measures (21–23). The present study adds controlled trial data suggesting that AI-based feedback may provide additional benefit when integrated with standard physiotherapy. However, the interpretation should remain cautious because the study evaluated a short-term supervised intervention and did not assess long-term retention, home-based adherence, recurrence, cost-effectiveness, or patient usability.

Several limitations should be considered when interpreting these findings. First, the intervention lasted only four weeks, and no follow-up assessment was reported; therefore, the durability of pain reduction, functional improvement, and scapular kinematic correction remains uncertain. Second, the sample size was modest, with 30 participants in each group, and the sample was recruited from outpatient physiotherapy settings within one regional context, which may limit generalizability to broader populations, athletes, older adults, or patients with more complex shoulder pathology. Third, assessor blinding, allocation concealment, intervention fidelity monitoring, and adverse event reporting were not described in sufficient detail, which limits appraisal of risk of bias. Fourth, the AI system itself requires fuller technical reporting, including sensor placement, calibration, algorithmic logic, feedback thresholds, and prior validity testing, to allow reproducibility and independent evaluation.

Another important limitation is that the statistical reporting was based mainly on pre-post comparisons and post-intervention between-group differences. Although the available findings favor the experimental intervention, future analyses should prioritize between-group change scores or adjusted treatment effects using ANCOVA or mixed-model approaches, with 95% confidence intervals and prespecified primary outcomes. Reporting adherence, adverse events, minimal clinically important differences, and participant acceptability would further strengthen clinical interpretation. Future trials should also examine whether AI-assisted visual feedback can maintain benefits in home-based or hybrid

rehabilitation models, where the need for accurate unsupervised exercise performance is especially relevant (24–26).

Overall, the study provides promising evidence that AI-driven real-time visual feedback may enhance standard physiotherapy outcomes in shoulder impingement syndrome by improving scapular upward rotation and reducing pain-related disability. The findings support continued investigation of AI-assisted movement feedback as an adjunct to conventional rehabilitation, but larger, methodologically rigorous trials with longer follow-up, blinded assessment, detailed intervention reporting, and transparent technology validation are needed before routine clinical implementation can be recommended.

CONCLUSION

The study concluded that AI-driven real-time visual motion feedback, when added to standard physiotherapy, produced greater short-term improvements in pain intensity, shoulder-related disability, and scapular upward rotation than standard physiotherapy alone in patients with shoulder impingement syndrome. The findings suggest that feedback-assisted correction of scapular movement may enhance the clinical value of conventional rehabilitation by improving movement accuracy and supporting better functional recovery. However, larger randomized trials with longer follow-up, detailed reporting of the AI system, assessor blinding, adherence monitoring, and adverse event documentation are required to confirm the durability, safety, reproducibility, and clinical applicability of this intervention.

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