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Graded motor imagery as an adjunct to comprehensive physiotherapy in chronic rotator cuff-related pain: a single blind randomized controlled trial

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Abstract

Background Chronic rotator cuff-related shoulder pain (C-RCRSP) may involve central sensitization and cortical changes. Graded motor imagery (GMI) targets these mechanisms, but its use in C-RCRSP is underexplored.

Objective This study aims to evaluate the effects of GMI to comprehensive physiotherapy on pain, mechanical sensitivity, laterality judgment, motor imagery ability, central sensitization symptoms, two-point discrimination, pain-related fear and patient satisfaction in patients with C-RCRSP.

Methods In this single-blind randomized controlled trial, 30 participants with C-RCRSP were randomized into two groups: comprehensive physiotherapy alone (CP) or combined with GMI (CP + GMI). Interventions were delivered twice weekly for six weeks. Outcomes included pain intensity, mechanical sensitivity, two-point discrimination, functionality, laterality judgment, motor imagery ability, central sensitization symptoms, pain-related fear and patient satisfaction.

Results Both groups showed significant within-group improvements in pain intensity, range of motion, functionality, and pain-related fear ($p < 0.05$). The CP + GMI group demonstrated earlier reductions in pain intensity and improvements in mechanical sensitivity, laterality judgment, motor imagery skills ($p < 0.05$). No significant differences were found within or between groups in central sensitization symptoms and two-point discrimination ($p > 0.05$). A higher proportion of participants in CP + GMI rated their recovery as "much better" compared to CP ($p = 0.05$).

Conclusion This study highlights that both groups showed significant improvements in pain, range of motion, functionality, and pain-related fear. However, adding GMI therapy led to faster pain relief, better mechanical sensitivity, improved motor imagery skills, and greater treatment satisfaction, warranting further research with larger samples and extended follow-ups to confirm its broader applicability.

Trial registration The study was approved by the local ethics committee (Reference No. ATADEK- 2023/21–13) and registered as a US National Library of Medicine Clinical Trial (Registration No: NCT06092489, Date: 13.10.2023).

Keywords Shoulder pain, Chronic pain, Rotator cuff injuries, Pain thresholds, Central nervous system sensitization, Imagery, Mirror therapy, Rehabilitation

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Introduction

Shoulder pain is a prevalent musculoskeletal condition, affecting 16% of the population (Lucas et al., 2022), with a prevalence of 0.67% to 55.2% in communities and an annual incidence of 7.7 to 62 per 1000 persons [1–3]. It is the third most common musculoskeletal complaint in primary care [4]. Rotator cuff-related shoulder pain (RCRSP), covering various rotator cuff pathologies, accounts for 50–85% of cases [5, 6]. Chronicity is common, with 50% persisting beyond six months and 40% showing no improvement after a year despite treatment [7].

Chronic rotator cuff-related shoulder pain (C-RCRSP) significantly affects physical function and quality of life [8, 9]. In some individuals with persistent symptoms, central sensitization (CS) and related neurophysiological mechanisms may contribute to the maintenance of chronic pain and disability. Although these mechanisms have not been specifically confirmed in C-RCRSP, evidence from other chronic musculoskeletal pain conditions suggests they may also play a role in this population [10, 11]. Studies in chronic pain populations have shown that pain can induce motor cortex changes, impair motor control and muscle activation [12], and reduce cortical excitability [13–15]. Furthermore, reorganization of the somatosensory cortex and increased activation of emotion- and fear-related brain areas—such as the anterior cingulate and insular cortices—have also been observed in chronic pain states [16, 17]. These central mechanisms may help explain persistent symptoms in certain subgroups of patients with C-RCRSP, particularly those with a hypersensitive clinical profile. Addressing such neurophysiological processes through strategies like graded motor imagery (GMI) may therefore enhance treatment outcomes beyond traditional physiotherapy approaches [18, 19].

GMI is a therapeutic approach that has demonstrated success in conditions associated with CS [20–22]. Its primary aim is to promote sensory and motor cortex reorganization, leading to reductions in pain intensity and changes in cerebral areas responsible for discriminative pain processing, as observed in functional MRI studies [23]. GMI involves three stages: laterality training, imagined movements, and mirror therapy. Each stage targets specific cortical mechanisms to reduce cortical disinhibition and reorganize neural pathways without triggering pain-related protective responses [22, 23]. While GMI has shown promising results in some patients with conditions such as complex regional pain syndrome and neurological disorders, its effects remain limited and variable [20, 21, 24, 25], and its application in musculoskeletal conditions, including rotator cuff injuries and chronic shoulder pain, is less explored.

Most studies investigating GMI's effects on shoulder pain have focused on conditions like frozen shoulder [26–29] or generalized shoulder pain [19, 30]. Only two studies have examined GMI's effects in patient populations similar to those in this study. Malik et al. (2018) [18] evaluated GMI's impact on pain and disability in rotator cuff injuries but did not distinguish between acute and chronic cases. Similarly, Araya-Quintanilla et al. (2020) [19] included patients with chronic shoulder pain but lacked a control group and used a non-randomized design. This study seeks to address these gaps by investigating the additive effects of GMI combined with a comprehensive physiotherapy program, which includes manual therapy, rotator cuff strengthening, scapular strengthening, and static/dynamic motor control exercises, in patients with C-RCRSP. We hypothesized that combining graded motor imagery with comprehensive physiotherapy would result in greater improvements in pain intensity, mechanical sensitivity, shoulder function, motor imagery ability, and cortical representation compared to physiotherapy alone in patients with C-RCRSP. The study evaluated pain levels, mechanical sensitivity, range of motion, two-point discrimination, functionality, and pain-related fear. Using a single-blind randomized controlled trial design, it aimed to provide robust evidence for incorporating GMI into rehabilitation programs for patients with C-RCRSP.

Methods

Study design

The present study was designed as a prospectively registered, controlled, single-blind randomized clinical trial and conducted between October 2023 and May 2024 at the Orthopaedic Rehabilitation Clinic of Dokuz Eylül University. With a two-arm parallel design and allocation concealment, the study ensured that the physiotherapist conducting the assessments, the researcher performing the statistical analyses, and the participants were all blinded to group allocations and the treatment program details. All methodological procedures adhered to the Consolidated Standards of Reporting Trials (CONSORT) guidelines [31]. The study was approved by the local ethics committee (Reference No. ATADEK- 2023/21–13) and registered as a US National Library of Medicine Clinical Trial (Registration No: NCT06092489). In accordance with the Helsinki criteria, informed consent was obtained from all participants in both verbal and written form.

Participants

The study included 36 individuals with C-RCRSP who met inclusion criteria and presented to the Orthopedic and Rehabilitation Clinic between October 2023 and

April 2024. All participants underwent physical and radiological examinations by an orthopedic surgeon (O.B.). Eligibility required C-RCRSP lasting six months or more, consistent with the IASP definition of chronic pain as pain persisting beyond normal tissue healing time, typically longer than 3 to 6 months [32], a maximum pain score of 2/10 at rest, and positive results in at least three of five pain tests (Neer, Hawkins-Kennedy, Jobe, painful arc 60°–120°, or external rotation resistance), followed by MRI confirmation of rotator cuff pathology [8, 33, 34]. A Mini-Mental State Examination score of ≥ 24 was also required [35]. Exclusion criteria included bilateral pain, corticosteroid injections within six weeks, overhead sports > 4 h/week, complete rotator cuff ruptures, calcifications > 5 mm, adhesive capsulitis with ≥ 30° loss of passive external rotation, cervical radiculopathy, or prior cervical, thoracic, or shoulder surgery. Participants with recent shoulder fractures/dislocations, pregnancy, inflammatory arthritis, neurological disorders, cancer, or chronic pain conditions commonly associated with central sensitization [36]—such as fibromyalgia, irritable bowel syndrome, chronic fatigue syndrome, temporomandibular joint disorder, migraine, or interstitial cystitis—were excluded. These conditions were excluded to avoid the confounding effects of widespread or multisystem pain mechanisms that may influence pain perception independently of localized shoulder pathology.

The sample size was calculated using G*Power version 3.1.7. Based on pain reduction outcomes reported in a previous graded motor imagery (GMI) study by Hoyek et al. (2004) [30], where the mean difference between groups was approximately 1.75 points on a 10-point pain scale with a pooled standard deviation of 1.56 (corresponding to Cohen's d ≈ 1.12), a total of 26 participants (13 per group) would be required to detect a significant between-group difference with 80% power and $\alpha = 0.05$ (two-tailed). To account for an estimated 25% dropout rate, the final target sample size was set at 36 participants (18 per group). The sample size was calculated to detect between-group differences in primary outcomes, which constituted the main research objective. While repeated measures ANOVA was used to examine interaction effects over time, these analyses were considered exploratory and complementary to the primary group comparisons.

Randomization and blinding

Participants were randomly assigned to one of two intervention groups (ratio: 1:1) using "Research Randomizer," an online randomization web service (https://www.randomizer.org). The groups were structured as follows:

i. Comprehensive Physiotherapy Group (CP group, $n = 18$)
ii. Comprehensive Physiotherapy and Graded Motor Imagery Group (CP + GMI group, $n = 18$)

Two sets of 18 random numbers were generated, with each number placed in a separate sealed envelope. After confirming eligibility, participants selected an envelope, and group assignments were determined based on the numbers inside. This process ensured a total of 36 participants in the study. Allocation was carried out by a secretary who was not involved in the study, and the assignment information was delivered to the physiotherapist responsible for administering the interventions (S.S.), as blinding was not feasible for the treatment provider. A second physiotherapist, blinded to group assignments, conducted pre- and post-treatment evaluations over the 6-week intervention period (assessor-blinded; H.A.Y.). To maintain participant blinding, treatments were scheduled on different days to ensure participants remained unaware of their group assignments and treatment content. Additionally, the researcher performing statistical analyses (N.A.) was blinded to group assignments to minimize bias during data analysis.

Although the physiotherapist delivering the intervention was not blinded, the outcome assessor and the data analyst were both blinded to participant group allocation. Participants were aware that they were receiving physiotherapy but were not informed about the specific nature of the GMI or which treatment was considered experimental. To minimize the potential for performance bias, intervention sessions were scheduled on separate days for each group (CP: Tuesdays and Fridays; CP + GMI: Mondays and Thursdays) to prevent contact or communication between participants in different groups.

Assessments

The general descriptive characteristics of the participants, including gender, age, height, weight, body mass index (BMI: kg/m^2), occupation, dominant side, and affected side, were recorded. The Numerical Pain Rating Scale (NPRS) and Pressure Pain Threshold (PPT) data were measured at baseline, at the end of the 1st week, the 2nd week, and the 6th week of treatment to evaluate the effects of GMI therapy stages on pain intensity and mechanical sensitivity. Other assessments were conducted at baseline and at follow-up (6 weeks after the end of treatment).

Primary outcome measures

Numerical Rating Scale (NPRS-11)

Pain intensity at rest, during activity, and at night in the shoulder joint was assessed using the Numeric Pain

Rating Scale (NPRS). This 11-point self-report scale ranges from 0 (no pain) to 10 (worst imaginable pain). It has shown excellent test–retest reliability [Intraclass Correlation Coefficient (ICC) = 0.92], with a minimal detectable change (MDC) of approximately 2 points and a minimal clinically important difference (MCID) of 2 points [37].

Shoulder Pain and Disability Index (SPADI)

The SPADI was used to assess pain and disability related to shoulder function. It consists of two subscales: Pain (5 items) and Disability (8 items). Each item on the Pain subscale was rated from 0 (no pain) to 10 (the worst pain imaginable), and each item on the Disability subscale was rated from 0 (no difficulty) to 10 (so difficult it requires help). In this study, all SPADI scores—including both subscale and total scores—were calculated as percentage scores, following the standard scoring procedure. Each subscale score was calculated by summing the item scores, dividing by the maximum possible score for that subscale, and multiplying by 100. The total SPADI score was similarly calculated using the sum of all 13 items. Higher scores indicate greater pain or disability. According to previous literature, the MCID for SPADI is reported to be 8–13 points on the 0–100 scale. This threshold was considered when interpreting the clinical relevance of group differences in outcome scores [38].

Central Sensitization Inventory (CSI)

The Central Sensitization Inventory (CSI) assesses symptoms associated with central sensitization through two parts. Part A includes 25 items scored on a 5-point Likert scale (0–4), with total scores ranging from 0 to 100. Scores ≥ 40 indicate a moderate severity of symptoms associated with central sensitization. Part B is a screening tool that records whether the participant has been previously diagnosed with any of the 10 medical conditions commonly associated with central sensitization (e.g., fibromyalgia, irritable bowel syndrome, migraine). In this study, Part B was used descriptively to identify and exclude participants with such diagnoses. The CSI has demonstrated excellent test–retest reliability (ICC = 0.87–0.91), with a MDC of approximately 5–10 points [39].

Global Rating of Change Scale (GRC)

The GRC assesses patient satisfaction with shoulder function improvement. Participants rate their condition after six weeks compared to baseline on a scale of −2 (much worse) to +2 (much better), with higher scores reflecting greater perceived improvement.

Secondary outcome measures

Shoulder Range of Motion (ROM) ROM was assessed using a universal goniometer (Baseline®) following standardized protocols. Participants were positioned supine, and movements were measured in various planes while ensuring a neutral chest position. The average of three consecutive measurements was recorded for accuracy. Shoulder ROM measurements using a goniometer have demonstrated high reliability, with ICC values typically exceeding 0.90 and standard error of measurement of approximately 5 degrees [40].

Pressure Pain Threshold (PPT) PPT, an indicator of mechanical sensitivity, was measured using a digital algometer (JTECH Commander Echo). Pressure was applied with a 1 cm^2 tip until participants reported pain by saying"stop."Three measurements were taken for each site with a 30-s interval, and the mean was recorded. PPT was assessed bilaterally on the middle deltoid and tibialis anterior. PPT assessment in the shoulder region has shown high test–retest reliability, with ICC values ranging from 0.80 to 0.97 depending on the muscle and site [8, 41].

Two-Point Discrimination Test (TPDT) TPDT was performed using a mechanical caliper (Aesthesiometer®) to measure tactile discrimination ability. The staircase method was used, increasing caliper distance by 2 mm until two points were perceived, and then reducing it until one point was reported. Assessments were performed on two shoulder sites: 5 cm from the acromion (C3-C4) and the lower deltoid insertion (C5-C6) [42, 43].

Left/Right Judgment Task (LRJT) Lateralization was evaluated using the Recognise™ Shoulder application (Noi Group). Participants identified left or right shoulders in 30 randomized images (context section) displayed on a tablet. Response time and accuracy were recorded. The LRJT using the Recognise™ Shoulder application has demonstrated excellent test–retest reliability for accuracy (ICC = 0.85) and reaction time (ICC = 0.80) [44].

Motor imagery ability Motor imagery ability was assessed using the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2). Participants visualized 12 actions, scoring vividness on a 5-point Likert scale (1 = as vivid as the original, 5 = no image). Scores were calculated for external visual, internal visual, and kinesthetic imagery, with higher scores indicating less vivid imagery. The VMIQ-2 has shown high internal consistency and test–retest reliability [45].

Fear Avoidance Beliefs Questionnaire (FABQ) The FABQ evaluates fear of movement, with sections for physical activity (5 items) and work (11 items). Responses are scored 0–6, with higher scores reflecting stronger fear-avoidance beliefs. Scores range from 0–24 for physical activity and 0–42 for work. For this study, "shoulder" replaced "back" in the original FABQ [26, 46, 47].

Pain Catastrophizing Scale (PCS) PCS measures the degree of catastrophic thinking related to pain through 13 items divided into helplessness, magnification, and rumination subscales. Each item is rated on a 0–4 Likert scale, with a total score range of 0–52. Higher scores reflect greater pain catastrophizing. The PCS has demonstrated excellent internal consistency and test–retest reliability, with ICC values ranging from 0.87 to 0.92. It is widely used to assess pain-related catastrophic thinking across clinical populations [48, 49].

Interventions

All interventions were conducted face-to-face at the Orthopaedic Rehabilitation Clinic of Dokuz Eylül University, a tertiary-level academic hospital equipped with private physiotherapy rooms, standard rehabilitation tools, and GMI-specific materials such as full-length mirrors, and tablet-based access to the Recognise™ Shoulder application. The interventions were delivered by a licensed physiotherapist (S.S.) with a Bachelor's degree in Physiotherapy and three years of clinical experience in musculoskeletal rehabilitation. The therapist had also completed postgraduate lessons in neurocognitive pain approaches. Fidelity to the intervention protocol was maintained through the use of a standardized treatment plan outlined in Table 1, with weekly oversight by a senior physiotherapist (N.A.). Patient adherence to the home-based exercise program was encouraged through written instruction, daily logs, and verbal check-ins at each session. Although home adherence data were not formally quantified, no protocol deviations or non-compliance were reported during the 6-week intervention period.

All participants received 12 sessions of physiotherapy over six weeks, at a frequency of two sessions per week. Each session lasted approximately 45 min and included therapeutic exercise, manual therapy, and patient education. Participants also received detailed instructions for home-based exercises, including guidance on sets, repetitions, rest intervals, and proper technique. They were instructed to perform the home exercise program once daily, completing three sets of 10–12 repetitions throughout the 6-week intervention period.

Comprehensive physiotherapy program

The program was described as"comprehensive physiotherapy"because each treatment session included a combination of several therapeutic approaches: manual therapy, rotator cuff strengthening, scapular strengthening, static and dynamic motor control exercises, and cold therapy [51].

Strengthening exercises were performed at a moderate intensity, which was monitored using the Borg Rate of Perceived Exertion (RPE) scale, targeting a perceived effort of 6–7 out of 10 (somewhat hard to hard). Exercise intensity and resistance were progressively increased based on patient tolerance, movement quality, and symptom response. The content of the sessions progressed weekly, starting with isometric and mobility-focused activities and advancing toward resistance-based functional exercises. A full breakdown of treatment content is provided in Table 1.

Graded motor imagery program

Participants in CP + GMI group received additional GMI interventions, consisting of three progressive stages delivered across the 12 sessions. These included:

- Stage 1: Laterality recognition training (Sessions 1–6) using the Recognise™ Shoulder app, with repeated left–right image identification tasks.
- Stage 2: Motor imagery (Sessions 3–8), in which participants mentally rehearsed shoulder movements derived from previously viewed postures.
- Stage 3: Mirror therapy (Sessions 7–12), where participants observed the unaffected limb in a mirror to create the illusion of pain-free movement in the affected shoulder.

Progression through the GMI stages was based on individual performance and comfort [19, 22, 26, 50]. Details are summarized in Table 1.

Statistical analysis

The statistical analysis was performed using SPSS 21.0 (IBM Corporation, Armonk, New York, USA). Continuous variables were presented as mean ± standard deviation (SD), while categorical variables were summarized as frequencies and percentages (%). The normality of the data was assessed using the Shapiro–Wilk test. Additionally, skewness and kurtosis values between −2 and +2 were considered indicative of a normal distribution. Since the data followed a normal distribution, parametric tests were employed for analysis. Baseline characteristics between the two independent groups were compared using the independent samples t-test for continuous

Table 1 Summary of treatment programs

Comprehensive Physiotherapy Program [51]

Session	Manual therapy	Rotator cuff strengthening	Scapular strengthening	Static/dynamic motor control
1	Scapular mobilization in side-lying (posterior tilt, upward rotation); Humeral traction in supine (posterior and inferior glide)	Pendulum exercises	Scapular orientation exercises	Correction of scapular position with visual, auditory, and tactile feedback during rest.
2	Wand-assisted ROM exercises in supine; Flexion and posterior capsule stretching.	Isometric internal/external rotation	Prone scapular retraction with extension and external rotation (I shape).	Scapular kinematics with feedback (side-lying)
3	Posterior capsule stretch in scapular plane using a wand.	External rotation (side-lying)	Prone external rotation	Scapular correction with feedback in the scapular plane in side-lying.
4	Self-stretching with a wand for pectoralis minor (progression from 0 to 90 degrees external rotation and abduction).	Wand exercises (45–120 degrees).	Prone shoulder external rotation and horizontal abduction (T shape).	Assisted active scapular kinematics training in the frontal plane in side-lying.
5	Posterior capsule stretching (sleeper stretch).	Isometric scapular exercises using a"finger ladder."	Wall slide exercises in a standing position (serratus wall slide)	Scapular kinematics training across all planes without feedback.
6	Towel-assisted self-stretching.	Theraband exercises (initial level).	Wall push-up (progression with incline angle) scapular exercises in a clockwise direction	Rhythmic stabilization in side-lying (initial-mid movement range).
7	Techniques from previous sessions.	Advanced Theraband exercises	Shoulder inferior glide in a standing position	Increased range of rhythmic stabilization in side-lying.
8	Techniques from previous sessions.	Prone external rotation and horizontal shoulder elevation.	Exercises from previous sessions.	Diagonal plane shoulder elevation with scapular reeducation.
9	Techniques from previous sessions.	Advanced Theraband exercises	Strengthening exercises with theraband targeting scapular retraction.	Alternating isometric exercises in the initial-mid range.
10	Techniques from previous sessions.	Strengthening exercises targeting the anterior rotator cuff (internal rotation) with theraband in 90-degree shoulder position.	Exercises from previous sessions.	Alternating isometric exercises for joint mobilization.
11	Techniques from previous sessions.	Closed kinetic chain exercises.	Progressed push-ups with knee and shoulder extension.	PNF exercises with theraband for scapular and shoulder movement.
12	Techniques from previous sessions.	Prone external rotation and extansion with the theraband.	Retraction exercises combined with trunk rotation and extension.	PNF exercises integrating trunk and lower extremities.

Graded Motor Imagery Program [16, 19, 26, 50]

Session	Stage 1: Laterality Recognition Training	Stage 2: Motor Imagery	Stage 3: Mirror Therapy
1–2	• Patients use the Recognise™ Shoulder app to train lateralization skills by distinguishing between left and right shoulder images. • Images are presented in four sections:"Basic,""Vanilla,""Context,"and"Abstract"with 20 images per Sect. (5-s intervals). • Patients complete 8 repetitions of 80 images daily (1 h total). • Response times and accuracy are recorded. • The goal is to achieve automatic recognition without hesitation or pain. This stage continues until lateralization accuracy is maintained for at least one week.	Not started.	Not started.

Table 1 (continued)

3–6	Continued laterality training for participants who haven't yet met the progression criteria.	• Patients mentally rehearse movements without physical execution, visualizing postures from the Recognise™ Shoulder app. • Each posture is imagined twice, and the process is repeated three times daily. • Progression is from simple to complex movements, focusing on vivid and precise visualization (e.g., imagining joint bending, tendon stretching, and skin folding). • Patients work in a calm environment (21–23 °C, dim lighting, with only the physiotherapist present). • If pain increases, patients return to Stage 1. • The goal is to reduce pain and improve motor imagery skills while maintaining comfort.	Not started.
7–12	Not applicable	7. Session: Final week of motor imagery: Progression to faster transitions and complex tasks. 8–12. Session: Completed.	• Patients observe the unaffected shoulder's movements in a mirror to create an illusion of pain-free movement in the affected shoulder. • Movements are performed in 8 specific postures from imagery training (, with each posture repeated twice, three times daily. • Patients focus on the mirror image rather than the unaffected shoulder directly. • Once patients can observe pain-free movements in the mirror, they begin synchronizing movements with the affected shoulder. • The aim is to enhance proprioceptive feedback, reverse cortical changes caused by pain, and promote neuroplasticity.

variables or the chi-square test for categorical variables. Changes within groups over time were analyzed using Repeated Measures ANOVA, assuming a fixed-effects model. Mauchly's test of sphericity was used to assess the assumption of variance–covariance homogeneity. When sphericity was violated, the Greenhouse–Geisser correction was applied. The main factors in the comparison of evaluation parameters were group and time. The comparison of evaluation parameters, with group and time (time ×group interaction) as main factors, was conducted using Mixed Model Repeated Measures ANOVA for NPRS (2 ×4), PPT values (2 ×3), and other data (2 ×2), with pre-treatment values as covariates. Post hoc analyses were conducted with Bonferroni correction, which is conservative for controlling Type I error. Although more powerful alternatives (e.g., Holm-Bonferroni, Benjamini-Hochberg) exist, Bonferroni was selected to ensure strict control of family-wise error rate given the exploratory nature of subgroup comparisons. The effect sizes were calculated using partial eta squared (η^2), with values interpreted as follows: 0.01–0.059 indicating a small effect, 0.06–0.139 a medium effect, and values ≥0.140 a large effect [52]. Changes within and between groups from baseline to the 6th week were reported with 95% confidence intervals (95% CI, lower–upper), and a p-value ≤0.05 was considered statistically significant.

Results

A total of 55 individuals were assessed for eligibility, with 19 excluded. Over six weeks, 15 participants in each group completed the study (Fig. 1). Demographic and baseline characteristics were similar between groups (p = 0.321–1.000, Table 2; p = 0.076–0.826, Table 3).

NPRS results (Fig. 2A–C) showed significant within-group improvements in both groups at week six compared to baseline, for shoulder pain at rest, during

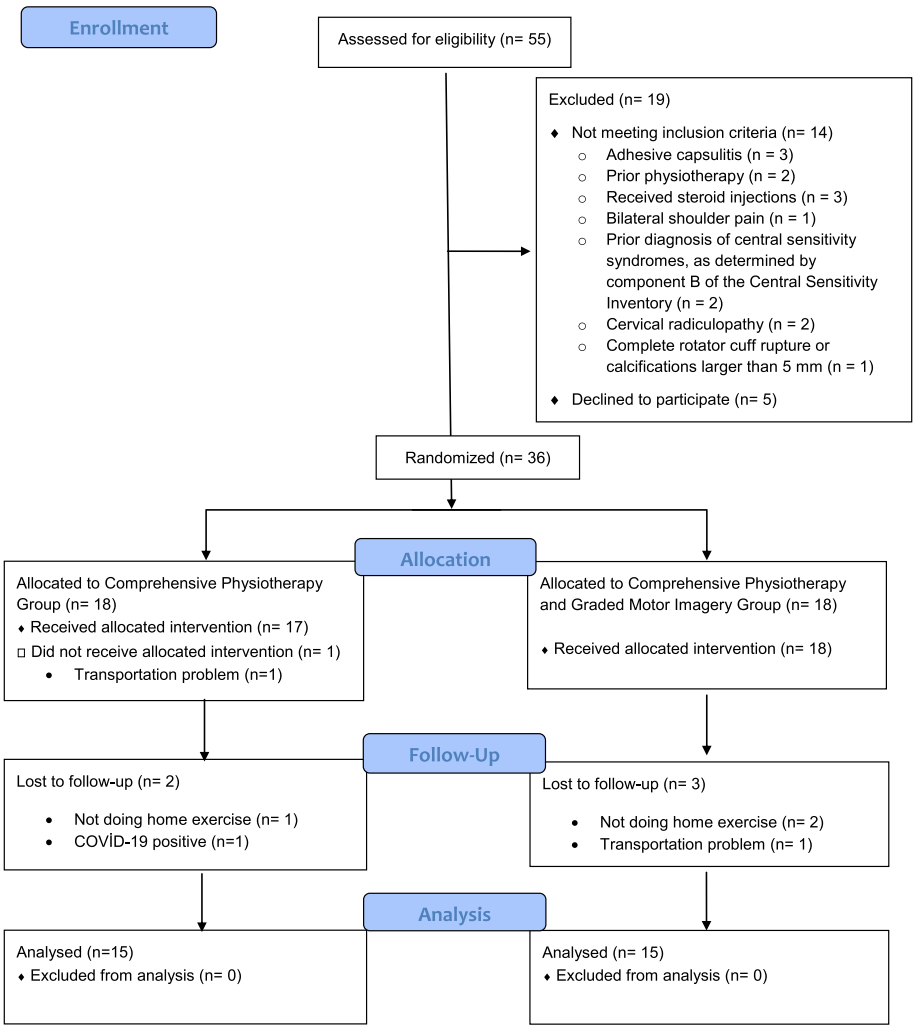

Fig. 1 Flow diagram

Table 2 Sociodemographic characteristics of the patients

Parameters	Comprehensive physiotherapy group ($n = 15$)	Comprehensive physiotherapy and graded motor imagery group ($n = 15$)	*P*-value
	Mean ± standard deviation or n (%)		
Age (years)	50.50 ± 09.52	47.50 ± 07.52	0.321[a]
Gender			
Female	7 (46.66%)	6 (39.99%)	0.713[b]
Male	8 (53.44%)	9 (60.01%)	
Disease Duration (months)	12.06 ± 04.21	13.47 ± 04.36	0.379[a]
Education Level (years)	12.20 ± 6.14	13.73 ± 5.51	0.478[a]
Dominant Side			
Right	15 (100.00%)	15 (100.00%)	1.000[b]
Left	0 (00.00%)	0 (00.00%)	
Symptomatic Side			
Right	9 (59.99%)	9 (59.99%)	1.000[b]
Left	6 (30.01%)	6 (30.01%)	
Occupation			
Employed	5 (33.33%)	7 (46.66%)	0.269[a]
Retired or homemaker	10 (72.67%)	8 (53.44%)	
Marital Status			
Married	10 (72.67%)	11 (73.44%)	0.690[b]
Single	5 (33.33%)	4 (26.66%)	
Smoking Status			
Smoker	6 (30.01%)	7 (46.66%)	0.709[b]
Non-Smoker	9 (59.99%)	8 (53.44%)	

[a] Student's t-test

[b] Chi-square test

activity, and at night (NPRS-Rest, NPRS-Activity, and NPRS-Night) ($p < 0.01$ for all). In the CP + GMI group, pain at rest (Fig. 2A) and during activity (Fig. 2B) showed a statistically significant reduction starting from the second week, which was sustained through the sixth week. For night pain (Fig. 2C), reductions became significant from Week 1 ($p = 0.015$), with stronger significance observed at Weeks 2 and 6 (all $p < 0.001$ for the CP + GMI group). In the CP group, improvements were only significant between baseline and Week 6 for pain at rest and during activity, while night pain showed significant improvement from Week 2 onwards ($p = 0.023$ and $p = 0.011$). However, there were no statistically significant between-group differences in any of the NPRS measures at Week 6 ($p = 0.254$–0.717, Fig. 2A–C).

PPT results are presented in Fig. 2D–G. In the CP + GMI group, a significant increase in pressure pain threshold was observed at week 6 on the symptomatic side for both the deltoid muscle ($p = 0.004$, Fig. 2D) and the tibialis anterior ($p = 0.048$, Fig. 2E), whereas no significant change was observed in the CP group. On the asymptomatic side, the CP + GMI group showed no significant change in the deltoid muscle ($p = 0.058$, Fig. 2F), but a significant increase in the tibialis anterior ($p = 0.044$, Fig. 2G) was detected at week 6. Moreover, among the significant changes observed, between-group differences favored the CP + GMI group ($p = 0.030$–0.048, Fig. 2D–G).

ROM improved significantly within both groups ($p = 0.007$– < 0.001, Table 4), with no between-group differences ($p > 0.05$). In LRJT, CP + GMI showed significant improvements in recognition accuracy ($p = 0.015$) and response times ($p < 0.001$, Table 4).

SPADI scores for pain and disability significantly decreased in both groups ($p < 0.001$, Table 5), with no intergroup differences ($p > 0.05$). The CP + GMI group showed significant improvements in motor imagery ability across all domains ($p < 0.05$). Both groups showed reductions in pain-related fear (FABQ and PCS, $p < 0.05$), though intergroup differences were not significant (Table 5). No changes were observed in CSI ($p > 0.05$, Table 5).

Table 6 indicates that a higher proportion of patients in the CP + GMI group rated their recovery as"much better"(60% vs. 20% in the CP group), reflecting a trend favoring the CP + GMI group ($p = 0.050$, Table 6).

Table 3 Comparison of baseline measurements between groups

Parameters	Comprehensive physiotherapy group ($n = 15$) Mean ± standard deviation	Comprehensive physiotherapy and graded motor imagery group ($n = 15$)	P^a value
Numerical Pain Rating Scale (NPRS, 0–10 scale)			
Rest	4.87 ± 03.09	3.20 ± 02.47	0.132
Activity	6.53 ± 02.42	5.67 ± 02.55	0.348
Night	5.87 ± 03.44	5.27 ± 02.34	0.581
Pressure Pain Threshold (PPT, kilopascal)			
Asymptomatic side—deltoid muscle	47.73 ± 26.05	67.40 ± 26.74	0.051
Symptomatic side—deltoid muscle	53.80 ± 26.48	58.87 ± 23.10	0.581
Asymptomatic side—tibialis anterior	81.47 ± 28.38	90.87 ± 24.94	0.344
Symptomatic side—tibialis anterior	75.27 ± 27.67	85.87 ± 25.95	0.288
Range of Motion (ROM, degrees**)**			
Flexion	152.30 ± 18.80	156.70 ± 17.60	0.520
Abduction	137.00 ± 29.30	145.30 ± 20.10	0.371
External rotation	63.30 ± 21.00	65.00 ± 14.80	0.803
Internal rotation	62.30 ± 23.40	64.00 ± 17.30	0.826
Two-Point Discrimination (TPDT, millimeters)			
Symptomatic side (acromion)	17.90 ± 03.18	16.70 ± 04.20	0.587
Symptomatic side (deltoid muscle)	18.30 ± 03.03	17.70 ± 02.89	0.626
Left/Right Judgment Task			
Recognition Accuracy (Symptomatic side)	1.78 ± 00.51	1.53 ± 00.26	0.101
*Response Time (**milliseconds**, Symptomatic side)*	91.87 ± 07.64	90.87 ± 08.29	0.734
Recognition Accuracy (Asymptomatic side)	93.60 ± 07.72	94.93 ± 05.48	0.590
*Response Time (**milliseconds**, Asymptomatic side)*	1.77 ± 00.41	01.64 ± 0.38	0.366
Shoulder Pain and Disability Index [SPADI, percentage scores (0–100)**]**			
SPADI-Pain	71.90 ± 17.75	58.30 ± 22.76	0.076
SPADI-Disability	56.50 ± 22.50	45.80 ± 19.77	0.176
SPADI-Total	59.50 ± 21.61	50.70 ± 20.18	0.259
Motor Imagery Assessment- Vividness of Movement Imagery Questionnaire-2 (VMIQ-2, 12–60)			
External imagery	35.20 ± 07.94	32.00 ± 12.19	0.402
Internal imagery	36.53 ± 08.35	30.00 ± 09.69	0.058
Kinesthetic imagery	24.80 ± 12.62	19.00 ± 15.52	0.271
Fear-Avoidance Beliefs Questionnaire (FABQ)			
*FABQ-Physical activity (**0–24**)*	16.00 ± 07.39	12.30 ± 07.29	0.175
*FABQ-Work **(0–42)***	19.40 ± 16.80	14.50 ± 15.24	0.413
*FAB, Q-Total score (**0–66**)*	38.60 ± 18.86	24.90 ± 16.78	0.069
Pain Catastrophizing Scale (PCS)			
*PCS-Helplessness **(0–24)***	09.87 ± 06.45	09.07 ± 07.30	0.753
*PCS-Magnification **(0–12)***	06.33 ± 02.97	04.60 ± 03.72	0.169
*PCS-Rumination **(0–16)***	08.60 ± 04.75	05.33 ± 05.39	0.089
*PCS-Total (**0–52**)*	24.80 ± 12.62	19.00 ± 15.52	0.271
Central Sensitization Inventory (CSI, 0–100)			
Total score	39.20 ± 12.69	34.07 ± 11.57	0.607
Present [n, %]	7 (46.66%)	10 (72.67%)	0.456
Absent [n, %]	8 (53.44%)	5 (33.33%)	

[a] Student's t-test

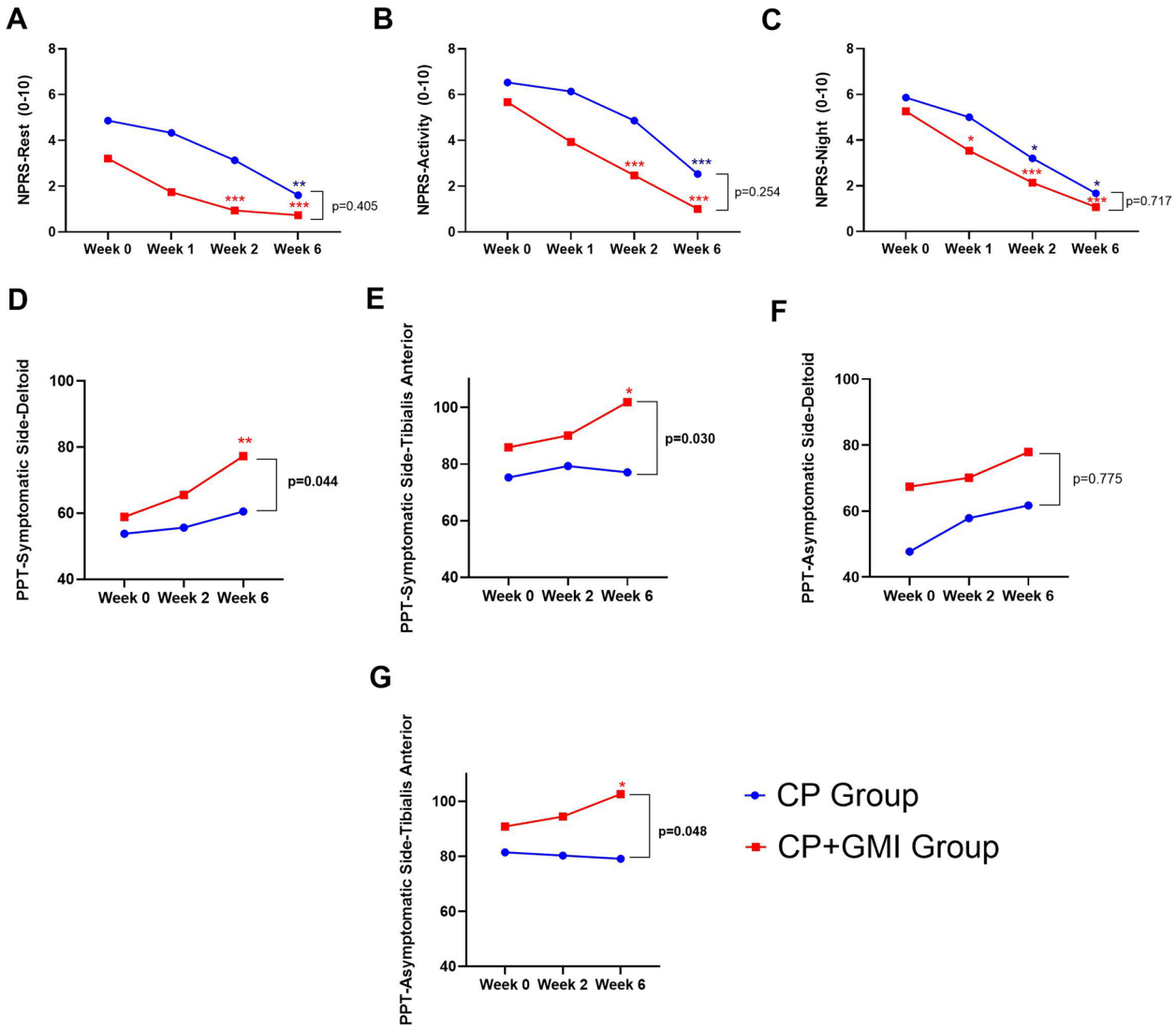

Fig. 2 Numerical Pain Rating Scale (NPRS) and Pressure Pain Threshold (PPT) Parameters. Within-group comparisons were conducted using repeated measures ANOVA with Bonferroni correction, while between-group comparisons were performed using 2 × 4 Mixed Model Repeated Measures ANOVA for NPRS and 2 x 3 Mixed Model Repeated Measures ANOVA for PPT; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Discussion

This study is the first randomized controlled trial investigating the effect of adding GMI to traditional physiotherapy in C-RCRSP. Both groups demonstrated statistically significant within-group improvements in pain intensity, range of motion, functionality, and pain-related fear. Although there were no significant between-group differences at the 6-week endpoint, the addition of GMI therapy to comprehensive physiotherapy appeared to lead to earlier reductions in pain intensity and improvements in mechanical sensitivity, laterality judgment, motor imagery skills, and treatment satisfaction compared to the comprehensive physiotherapy group alone.

C-RCRSP can be explained by peripheral inflammation and central sensitization mechanisms. The inflammatory processes that develop in tissues due to tendinopathy or tears result in the release of inflammatory mediators such as prostaglandins, cytokines, and bradykinin, which amplify pain [53]. Chronic pain induces central sensitization through increased synaptic activation of neurotransmitters like glutamate and substance P in the spinal dorsal horn and brain [54]. These processes lead to widespread pain perception and increased sensitivity [55]. Cortical reorganization occurs in the somatosensory and motor cortices, causing the generation of aberrant signals from the painful area and resulting in outcomes such as

Table 4 Intragroup and intergroup comparison of range of motion, left/right judgment task and two-point discrimination parameters

Parameters	Groups	Before treatment	After treatment	Within-group score change	Effect size	Intragroup evaluation (p)[a]	Intergroup evaluation (p)[b]
		Mean ± standard deviation	Mean ± standard deviation	[mean difference (95% CI, lower–upper)]			
Range of Motion							
Flexion	*CP group*	152.33 ± 18.79	169.67 ± 9.54	−17.33 (−25.60–09.07)	0.699	**< 0.001**	0.510
	CP + GMI group	156.67 ± 17.59	177.33 ± 3.72	−20.67 (−31.43–09.90)	0.660	**< 0.001**	
Abduction	*CP group*	137.00 ± 29.26	164.67 ± 21.00	−27.67 (−39.66–15.68)	0.737	**< 0.001**	0.744
	CP + GMI group	145.33 ± 20.13	175.33 ± 6.11	−30.00 (−45.00–14.99)	0.678	**< 0.001**	
External rotation	*CP group*	63.33 ± 21.02	77.00 ± 13.86	13.67 (−23.54–03.79)	0.503	**0.002**	0.641
	CP + GMI group	65.00 ± 14.76	81.00 ± 7.61	16.00 (−25.11–06.89)	0.619	**< 0.001**	
Internal rotation	*CP group*	62.33 ± 23.37	80.33 ± 15.41	13.67 (−23.54–03.79)	0.694	**0.007**	0.627
	CP + GMI group	64.00 ± 17.34	85.00 ± 7.07	16.00 (−25.11–06.89)	0.496	**< 0.001**	
Left/Right Judgment Task							
Recognition Accuracy (symptomatic side)	*CP group*	91.87 ± 7.64	92.47 ± 8.21	0.60 (−8.50–07.30)	0.003	0.839	0.132
	CP + GMI group	90.87 ± 8.29	97.20 ± 2.57	6.33 (−12.51–00.16)	0.357	**0.015**	
Response Time (ms, symptomatic side)	*CP group*	1.78 ± 0.51	1.67 ± 0.33	−0.11 (−0.19–00.40)	0.329	0.068	**0.012**
	CP + GMI group	1.53 ± 0.26	1.05 ± 0.23	−0.47 (−0.25–00.70)	0.707	**< 0.001**	
Recognition Accuracy (asymptomatic side)	*CP group*	93.60 ± 7.72	94.93 ± 5.48	−1.80 (−04.59–08.19)	0.040	0.457	0.142
	CP + GMI group	91.80 ± 8.65	97.33 ± 3.33	2.40 (−06.44–01.64)	0.157	0.129	
Response Time (ms, asymptomatic side)	*CP group*	1.77 ± 0.42	1.6 (1.2–2.6)	−0.07 (−00.16–00.30)	0.052	0.354	**0.002**
	CP + GMI group	1.64 ± 0.38	1.10 ± 0.20	−0.54 (0.26–00.82)	0.666	**< 0.001**	
Two-Point Discrimination							
Symptomatic side (acromion)	*CP group*	27.73 ± 7.37	27.00 ± 7.93	−0.20 (−0.93–01.33)	0.010	0.710	0.467
	CP + GMI group	27.53 ± 8.34	26.20 ± 8.36	−0.80 ± (−2.13–0.53)	0.107	0.217	
Asymptomatic side (deltoid muscle)	*CP group*	18.27 ± 3.03	17.60 ± 3.64	−0.67 (−0.21–01.55)	0.160	*0,126*	1.000
	CP + GMI group	17.73 ± 2.89	17.07 ± 3.79	−0.67 (−0.75–02.08)	0.680	*0,330*	

CI confidence interval, *CP group* Comprehensive Physiotherapy Group, *CP + GMI group* Comprehensive Physiotherapy and Graded Motor Imagery Group

[a] repeated measurements

[b] Two-way repeated measurements ANOVA; Post hoc analyses were conducted with Bonferroni correction; The effect sizes were calculated using partial eta squared (η^2), with values interpreted as follows: 0.01–0.059 indicating a small effect, 0.06–0.139 a medium effect, and values ≥ 0.140 a large effect. Bold values indicate statistical significance within the group or between groups

movement restrictions [16]. The observed improvements in pain, range of motion, functionality, and pain-related fear in both groups suggest that these processes may be reversed by both therapeutic approaches.

The early reduction in pain intensity (at weeks 2 and 3) observed only in the CP + GMI group can be attributed to GMI's ability to modulate central sensitization and reduce the amplification of pain signals (Moseley, 2004). These time points coincide with the completion of the laterality judgment and motor imagery phases of GMI. Laterality judgment activates the premotor cortex, reducing focus on the painful region and correcting somatosensory impairments affecting pain perception [22]. Motor imagery activates areas associated with movement planning, such as the primary motor cortex, reducing movement-related fear and alleviating pain [56]. Similarly, literature supports the role of GMI in reducing pain intensity during the early stages of shoulder pain [26].

At the end of the treatment (week 6), an increase in pressure pain threshold (PPT) values, which measure mechanical sensitivity, was observed only in the CP + GMI group. This finding indicates that GMI positively influences somatosensory cortex reorganization and sensory-motor integration [22]. The observed PPT increase in the tibialis anterior muscle further

Table 5 Intragroup and intergroup comparison of functionality, motor imagery ability and pain related fear parameters

Parameters	Groups	Before treatment	After treatment	Within-group score change	Effect size (n^2p)	Intragroup evaluation (p)[a]	Intergroup evaluation (p)[b]
		Mean ± standard deviation	Mean ± standard deviation	[mean difference (95% CI, lower–upper)]			
Shoulder Pain and Disability Index (SPADI)							
SPADI-Pain	*CP group*	71.87 ± 17.75	30.00 ± 19.74	−41.87 (29.55–54.18)	0.792	**< 0.001**	0.677
	CP + GMI group	58.27 ± 22.76	20.27 ± 17.74	−38.00 (22.67–53.36)	0.668	**< 0.001**	
SPADI-Disability	*CP group*	56.53 ± 22.50	22.27 ± 17.65	−34.27 (29.55–54.18)	0.723	**< 0.001**	0.882
	CP + GMI group	45.80 ± 19.77	10.33 ± 13.29	−35.47 (29.55–54.18)	0.740	**< 0.001**	
SPADI-Total	*CP group*	59,53 ± 21,61	26,13 ± 16,99	−33,40 (22,49–44,31)	0.014	**< 0.001**	0.650
	CP + GMI group	50,73 ± 20,18	13,67 ± 14,86	−37,07 (23,85–50,29)	0.345	**< 0.001**	
Motor Imagery Assessment							
External imagery	*CP group*	35.20 ± 7.94	35.53 ± 9.63	0.33 (−03.78–03.11)	0.003	0.839	**< 0.001**
	CP + GMI group	32.00 ± 12.19	20.47 ± 7.65	−11.53 (−16.89–06.19)	0.604	**< 0.001**	
Internal imagery	*CP group*	36.53 ± 8.35	34.80 ± 9.27	−2.73 (00.15–05.32)	0.219	0.051	**0.050**
	CP + GMI group	30.00 ± 9.69	21.20 ± 7.55	−8.80 (02.95–14.65)	0.426	**0.006**	
Kinesthetic imagery	*CP group*	35.93 ± 8.51	34.00 ± 9.72	−1.93 (−00.95–04.81)	0.129	**0.172**	**0.050**
	CP + GMI group	30.60 ± 11.57	18.47 ± 7.56	−12.13 (05.66–18.61)	0.536	**0.001**	
Fear-Avoidance Beliefs Questionnaire (FABQ)							
FABQ-Physical activity	*CP group*	16.00 ± 7.39	7.60 ± 6.23	−8.40 (22.49–44.31)	0.753	**< 0.001**	0.186
	CP + GMI group	12.27 ± 7.29	6.73 ± 8.61	−5.53 (22.49–44.31)	0.438	**0.010**	
FABQ-Work	*CP group*	19.40 ± 16.80	12.50 ± 14.52	−17.33 (−25.60–09.07)	0.699	**< 0.001**	0.510
	CP + GMI group	14.53 ± 15.24	7.25 ± 10.10	−20.67 (−31.43–09.90)	0.660	**< 0.001**	
FABQ-Total score	*CP group*	38.6 ± 18.86	22.67 ± 18.46	−17.20 (09.73–24.61)	0.754	**< 0.001**	0.275
	CP + GMI group	24.87 ± 16.78	12.25 ± 13.36	−10.92 (01.42–20.41)	0.368	**0.028**	
Pain Catastrophizing Scale (PCS)							
PCS-Helplessness	*CP group*	9.87 ± 6.45	6.27 ± 5.46	−3.60 (01.79–05.41)	0.565	**< 0.001**	0.201
	CP + GMI group	9.07 ± 7.30	3.13 ± 4.26	−5.93 (02.57–09.30)	0.505	**0.002**	
PCS-Magnification	*CP group*	6.33 ± 2.97	3.47 ± 2.97	−2.87 (01.43–04.30)	0.568	**< 0.001**	0.788
	CP + GMI group	4.60 ± 3.72	2.07 ± 3.28	−2.53 (00.33–04.73)	0.303	**0.027**	
PCS-Rumination	*CP group*	8.60 ± 4.75	4.47 ± 4.21	−4.13 (02.37–05.89)	0.644	**< 0.001**	0.433
	CP + GMI group	5.33 ± 5.39	2.47 ± 4.63	−2.87 (00.14–05.87)	0.257	**0.050**	
Central Sensitization Inventory (CSI)	*CP group*	39.20 ± 12.69	36.53 ± 13.14	2.66 (−1.09–06.43)	0.142	0.150	0.942
	CP + GMI group	34.07 ± 11.57	31.20 ± 09.77	2.87 (−1.60–07.37)	0.119	0.190	

CI confidence interval, *CP group* Comprehensive Physiotherapy Group, *CP + GMI group* Comprehensive Physiotherapy and Graded Motor Imagery Group, *VMIQ-2* Vividness of Movement Imagery Questionnaire-2, All SPADI values are expressed as percentage scores (0–100), not raw totals

[a] repeated measurements

[b] Two-way repeated measurements ANOVA; Post hoc analyses were conducted with Bonferroni correction; The effect sizes were calculated using partial eta squared (η^2), with values interpreted as follows: 0.01–0.059 indicating a small effect, 0.06–0.139 a medium effect, and values ≥ 0.140 a large effect. Bold values indicate statistical significance within the group or between groups

demonstrates that GMI provides systemic, not just localized, pain modulation [23].

Previous studies have shown impairments in left/right judgment [27, 44, 57] and motor imagery ability [58–60] in individuals with chronic pain compared to asymptomatic individuals. These impairments are thought to be the result of central nervous system changes induced by chronic pain. Graded Motor Imagery (GMI) aims to reorganize these neuroplastic changes through its structured stages. The left/right judgment exercises in GMI specifically activate the premotor cortex, improving speed and accuracy in discrimination tasks [23]; motor imagery activates both the primary and premotor cortices, enhancing movement planning and strengthening

Table 6 Global rating of change scores after treatment

Global rating of change	Comprehensive physiotherapy group ($n=15$), *n* (frequency %)	Comprehensive physiotherapy and graded motor imagery ($n=15$) *n* (frequency %)	P^a value
− 2 (Much worse)	0	0	**0.050**
− 1 (Worse)	0	0	
0 (Same)	0	0	
1 (Better)	12 (80.00%)	6 (40.00%)	
2 (Much better)	3 (20.00%)	9 (60%)	

Bold values indicate statistical significance within the group or between groups

[a] Chi-square test

cortical connections [22, 23]; and mirror therapy engages visual and sensorimotor feedback to alter cortical representation and reduce pain perception [21]. Consistent with these mechanisms, significant improvements in left/right judgment and motor imagery skills were observed in the CP + GMI group, but not in the CP group. This is an expected result, as the GMI program directly targets the development of these neurocognitive abilities through specialized exercises. However, both groups demonstrated similar improvements in pain intensity, sensitivity, and function. Therefore, although GMI improved cognitive and sensorimotor processing, these benefits may not have translated into additional clinical advantages within the short duration of the intervention. Additionally, the CP + GMI group presented with slightly better baseline values in some outcome measures, which may have contributed to a faster clinical response. Hence, the observed early improvements in the CP + GMI group should be interpreted with caution and further validated in studies with larger sample sizes and more balanced baseline characteristics.

Higher treatment satisfaction in the CP + GMI group can be attributed to the early reduction in pain and positive changes in perceptual processes. Specifically, the laterality and motor imagery phases contribute to faster perceptual pain relief [23]. Such early effects likely increase patients' confidence in the treatment process, enhancing satisfaction. Methods like mirror therapy, which improve perception of painful areas and boost treatment confidence, support this finding [61].

Irritable RCRSP is characterized by intense symptoms in the early stages due to a low pain threshold and heightened tissue sensitivity. This often limits physiotherapy options until pain is reduced. The observed reduction in pain and mechanical sensitivity with GMI in this study suggests that GMI may be particularly useful for managing symptoms in the early phase of treatment, even though longer-term outcomes were similar between groups. However, since no distinction was made between hypersensitive and less sensitive patients, findings need validation with more specific samples.

Although both groups demonstrated similar improvements in range of motion, functionality, and pain-related fear, these outcomes were limited to week 6 evaluations. Earlier evaluations, as done for pain, might have revealed different results, representing the first limitation of this study. The second limitation is the small sample size, which may have hindered the detection of small but clinically significant differences, affecting generalizability due to individual variability in outcomes. The third limitation is the lack of blinding of the physiotherapist administering the interventions, which could have introduced unintentional bias. Fourth, the limited clinical application of GMI and its effective use requiring experienced physiotherapists restricts the study's external validity. Fifth, the absence of a placebo control group prevents ruling out placebo-related effects in the observed improvements**.** Finally, the lack of long-term follow-up and the use of subjective assessment tools, which may be influenced by participant perceptions, also constitute limitations. Moreover, although baseline group differences were not statistically significant, slightly better initial scores in the CP + GMI group may have influenced the speed of recovery.

Conclusions

This study demonstrates that both treatment groups achieved significant improvements in pain intensity, range of motion, functionality, and pain-related fear. However, there were no statistically significant between-group differences in primary outcome measures at the 6-week post-treatment point. While GMI therapy was associated with earlier improvements in pain, mechanical sensitivity, laterality judgment, motor imagery ability, and treatment satisfaction, these benefits appeared to be short-term.

These results suggest that GMI may serve as a valuable adjunctive therapy to enhance early-phase rehabilitation outcomes in patients with hypersensitive RCRSP, particularly for modulating neurocognitive and sensorimotor parameters. However, the lack of sustained differences at post-treatment indicates that GMI's benefit may be time-limited rather than indicative of superior overall efficacy. Further research with larger samples, placebo controls, and long-term follow-up is warranted to confirm and expand on these findings.

Abbreviations

CP group	Comprehensive Physiotherapy Group
CP + GMI group	Comprehensive Physiotherapy and Graded Motor Imagery Group
CP	Central sensitization
C-RCRSP	Chronic rotator cuff-related shoulder pain
CSI	Central Sensitization Inventory
FABQ	Fear Avoidance Beliefs Questionnaire
GMI	Graded motor imagery
GRC	Global Rating of Change Scale
ICC	Intraclass Correlation Coefficient
LRJT	Left/Right Judgment Task
MCID	Minimal Clinically Important Difference
MDC	Minimal Detectable Change
NPRS	Numerical Pain Rating Scale
PCS	Pain Catastrophizing Scale
PPT	Pressure Pain Threshold
RCRSP	Rotator cuff-related shoulder pain
ROM	Range of Motion
SPADI	Shoulder Pain and Disability Index
TPDT	Two-Point Discrimination Test
VMIQ-2	Vividness of Movement Imagery Questionnaire-2

Authors' contributions

Seda Sırlan: Writing – Original Draft, Formal analysis, Data Curation, Conceptualization, Writing - Review & Editing, Conceptualization; Nuray Alaca: Writing – Original Draft, Formal analysis, Conceptualization, Writing - Review & Editing, Conceptualization, Project administration; Hacı Ahmet Yarar: Conceptualization, Data Curation; Onur Başçı: Formal analysis, Conceptualization, Data Curation. All authors reviewed the manuscript.

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Data availability

All data generated or analyzed during this Research period are included in published articles. Data are available on request to the authors.

Declarations

Ethics approval and consent to participate

The study was approved by the local ethics committee (Reference No. ATADEK- 2023/21–13) and registered as a US National Library of Medicine Clinical Trial (Registration No: NCT06092489, Date: 13.10.2023). In accordance with the Helsinki criteria, informed consent was obtained from all participants in both verbal and written form.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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