Yu et al. BMC Musculoskeletal Disorders (2025) 26:271
https://doi.org/10.1186/s12891-025-08496-0

BMC Musculoskeletal Disorders

SYSTEMATIC REVIEW

Open Access

Evaluating the impact of movement representation techniques on recovery outcomes in post-orthopaedic surgery individuals: a systematic review and meta-analysis

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Abstract

Background Although movement representation techniques has originally been used in neurological rehabilitation, growing researches suggests that it may also introduce advantageous effects to individuals with orthopaedic injuries. This systematic review and meta-analysis aimed to investigate the effects of these techniques on pain, range of motion, muscle strength, functional performance and fear of movement in individuals after orthopaedic surgeries.

Method Five electronic databases were searched until April 2024. Two reviewers independently conducted study selection and data extraction. Randomized controlled studies containing individuals after limb surgeries were identified. The quality of enrolled studies and the overall certainty of evidence was assessed by scales, respectively. Egger's test and funnel plot were used to assess publication bias. Subgroup analysis was also conducted to explore the source of heterogeneity.

Results Twenty-one randomized controlled trials involving 659 postsurgical participants were identified. The meta-analysis suggested moderate-quality evidence of a positive effect on pain intensity (SMD=-0.85; 95% CI -1.26, -0.43; $p<0.001$). A low quality of evidence pointed toward a positive effect on functional scales (SMD=-0.84, 95% CI -1.27, -0.41, $p<0.001$) and range of motion (SMD = 0.8, 95% CI 0.24, 1.35, $p=0.005$). The very low quality of evidence suggested a significant effect on the functional test results (SMD=-0.8, 95% CI -1.01, -0.58, $p<0.001$). The results remained nonsignificant for muscle strength and fear of movement. Intervention quantity, Disability of Arm, Shoulder, and Hand (DASH) score and intervention content were the sources of heterogeneity for pain intensity, functional scale score and range of motion, respectively.

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Conclusion Compared with conventional rehabilitation, movement representation techniques increase pain relief, functional performance and range of motion. Our results support the use of mental practice techniques in individuals after orthopaedic surgeries, with moderate to very low-quality evidence.

Review registration This trial was registered on PROSPERO on 10 August, 2024 (CRD42024583380).

Keywords Orthopaedic rehabilitation, Movement representation techniques, Pain

Introduction

Appropriate orthopaedic rehabilitation is the key factor in determining the postoperative prognosis of individuals. It involves a structured program of physical therapy that begins shortly after the surgical procedure to ensure optimal recovery, reduce complications, and shorten hospital stays [1–3]. Guidelines from the American Academy of Orthopaedic Surgeons and the American Physical Therapy Association highlight the critical role of supervised physiotherapy and occupational therapy throughout the continuum of clinical care [4, 5]. Orthopaedic rehabilitation usually involves edema control, pain relief, joint mobilization, and strengthening exercise. As recovery progresses, activities of daily living are also involved.

Movement representation techniques are new rehabilitation approaches that involve the use of representations of movement, such as observing and imagining painless movements [6]. In this case, mirror therapy, motor imagery and action observation are all categorized as movement representation techniques. In mirror therapy, participants sit in front of the mirror and observe the reflection of the intact limb to create visual illusion in the brain and divert participants' attention from the affected limbs to the intact limbs. Action observation refers to watching actions performed by others. Motor imagery is defined as mind rehearsal of various motors without actual execution. This implies that the individuals are executing the movements. Graded motor imagery further develops on the basis of these two components [7]. It consists of three sequential strategies: left-and-right discrimination (phase one), motor imagery (phase two), and mirror therapy (phase three). It is designed to gradually increase cortical activation and reduce cortical disinhibition [8].

Although movement representation techniques were originally used in neurological rehabilitation, a growing body of research suggests that they may also introduce advantageous effects to individuals with orthopaedic injuries, since individuals without cognitive deficits may benefit from mental practice techniques at the maximum level [9]. Recently, seven meta-analyses have investigated the effects of motor imagery/graded motor imagery in musculoskeletal disorders [6, 10–15]. The results are inconsistent: three studies reported the beneficial effect of pain relief [6, 12, 13], whereas four studies reported no improvement in pain [10, 11, 14, 15]. The seven reviews included subjects with conditions such as ankle sprains, shoulder impingement, anterior cruciate ligament reconstruction, and total knee joint replacement. These subjects underwent either conservative treatment or surgical intervention. However, movement representation techniques may exert different effects on acute, chronic, and postsurgical pain or other outcome measures [14]. To date, for postsurgical conditions, meta-analyses have been conducted only for total knee arthroplasty [16–18]. They consistently reported that mental stimulation was effective at improving pain and strength, but the discrepancy remained for range of motion and physical functional scale scores. Nonetheless, direct evidence specific to individuals after orthopaedic surgery is still lacking.

The main aim of the present systematic review and meta-analysis was to investigate the effects of movement representation techniques, such as mirror therapy, action observation, motor imagery and graded motor imagery, on pain, range of motion, muscle strength, functional performance and kinesiopobia in individuals after orthopaedic surgery. We hypothesized that such outcome measures would be greatly improved.

Method

This systematic review and meta-analysis was prospectively registered in the International Prospective Register of Systematic Reviews (CRD42024583380) and was developed following PRISMA guidelines [19].

Search strategy

Randomized controlled studies from the following five databases were searched until April 2024: PubMed, Scopus, EMBASE, the Cochrane Library Database and EBSCOhost. The search strategy included terms related to motor imagery, mirror therapy, action observation, graded motor imagery, pain, range of motion, muscle strength, and randomized controlled trials. The search strategy of all databases were summarized in the Appendix. The references of previous systematic reviews were also screened for eligibility.

Eligibility criteria

The inclusion criteria for the literature were as follows: (1) individuals who underwent orthopaedic surgery; (2) individuals whose graded motor imagery, motor imagery, mirror therapy, action observation or other movement representation techniques were used as interventions; (3) individuals whose pain, function scale/test, range of motion or muscle strength was used as an outcome measure; (4) study design was a randomized controlled trial; (5) individuals whose conventional rehabilitation or sham therapy was used in the control group; and (6) research articles reported in English. The exclusion criteria for the literature were as follows: (1) individuals who underwent conservative treatment after orthopaedic injury; (2) individuals who underwent spinal surgery; and (3) articles that were protocols and abstracts only.

Study selection and data extraction

First, two authors (XY and HJW) independently screened titles and abstracts after duplicate removal. When the inclusion and exclusion criteria were met, full-text screening was performed. After the included literature was determined, data extraction was accordingly carried out by XY and JXW. The extracted information followed the PICO principle and included author, year, country, number of subjects in each group, age, type of surgery, exercise in the experimental group, exercise in the control group, intervention frequency, intensity, duration, outcome measures, and main findings. Any disagreements were resolved through group meetings with the three reviewers (XY, HJW, and JXW). One author (XY) additionally searched the reference lists of relevant systematic reviews to avoid any missing data.

Study quality assessment

The methodological quality assessment of the included studies was independently rated by XY and HJW using the Physiotherapy Evidence Database (PEDro) scale. PEDro is a reliable and valid tool for evaluating the methodological quality of randomized controlled studies and has been widely adopted in physiotherapy and pharmaceutical research [20]. The PEDro scale consists of 11 items, and each item is evaluated according to "yes" or "no". The first item was the eligibility criterion; therefore, the total score was 10. The evaluation items included random allocation, concealed allocation, baseline comparability, blind subjects, blind therapists, blind assessors, adequate follow-up, intention-to-treat analysis, between-group comparisons, point estimates and variability. A higher score indicates better methodological quality. A score of 9–10 was classified as excellent, 6–8 as good, 4–5 as fair and 0–3 as poor quality [21].

Evidence rating

The overall certainty of evidence for the outcome measures was assessed via the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) [22]. The evidence level was rated as high, moderate, low or very low on the basis of the following principles: risk of bias (if more than 25% of participants were from studies scored lower than 6 in PEDro), inconsistency (if $I^2 > 50\%$), imprecision (the sample size of continuous variables was below 400), publication bias (reviewed with Egger's test and funnel plot), and indirectness (differences in intervention and outcome measures).

Statistical analysis

Meta-analyses were considered when the outcomes of 4 or more studies were comparable and were conducted in Review Manager 5.2 (RevMan). The I^2 statistic was used to assess heterogeneity across studies, with a value greater than 50% indicating significant heterogeneity [23]. If the I^2 was less than 50%, the fixed effects model was used; otherwise, the random effects model was used to calculate the differences between the experimental group and the control group. Egger's test and funnel plot were used to assess publication bias. Furthermore, given the diversity of intervention therapies and outcome measures, subgroup analysis was also conducted to explore the cause of heterogeneity. Kinesiophobia was presented with mean differences and 95% confidence intervals (95% CIs), and other outcome measures (pain, functional scales, muscle strength, functional tests and range of motion) were presented as standard mean differences with 95% CIs via forest plots. $P < 0.05$ was considered statistically significant.

Results

A total of 5341 articles were retrieved from five electronic databases. After duplicate removal and full-text screening, a total of 51 studies were initially identified for eligibility screening based on our inclusion criteria. However, only 21 of these studies were ultimately included in the meta-analysis, mainly because they were abstracts only and had incorrect settings. Figure 1 shows the study selection process and the reasons for exclusion. Twenty-one randomized controlled studies were published between 2009 and 2023 and included a total of 659 participants. There were 334 individuals in the experimental group and 325 individuals in the control group. Table 1 summarizes the characteristics of the included studies. Table 2 summarized the detailed intervention characteristics. The general description of four types of movement representation techniques were summarized in Table 3. Among these articles, eight included individuals who underwent total knee arthroplasty [9, 24–30], six enrolled individuals after hand reconstruction surgery or hand tendon repair [31–36], two included individuals who underwent anterior cruciate ligament reconstruction surgery [37, 38], and two enrolled individuals after total hip arthroplasty surgeries [39, 40]. The remaining two studies involved individuals with distal radius fracture surgery and posttraumatic stiffness of the elbow [41,

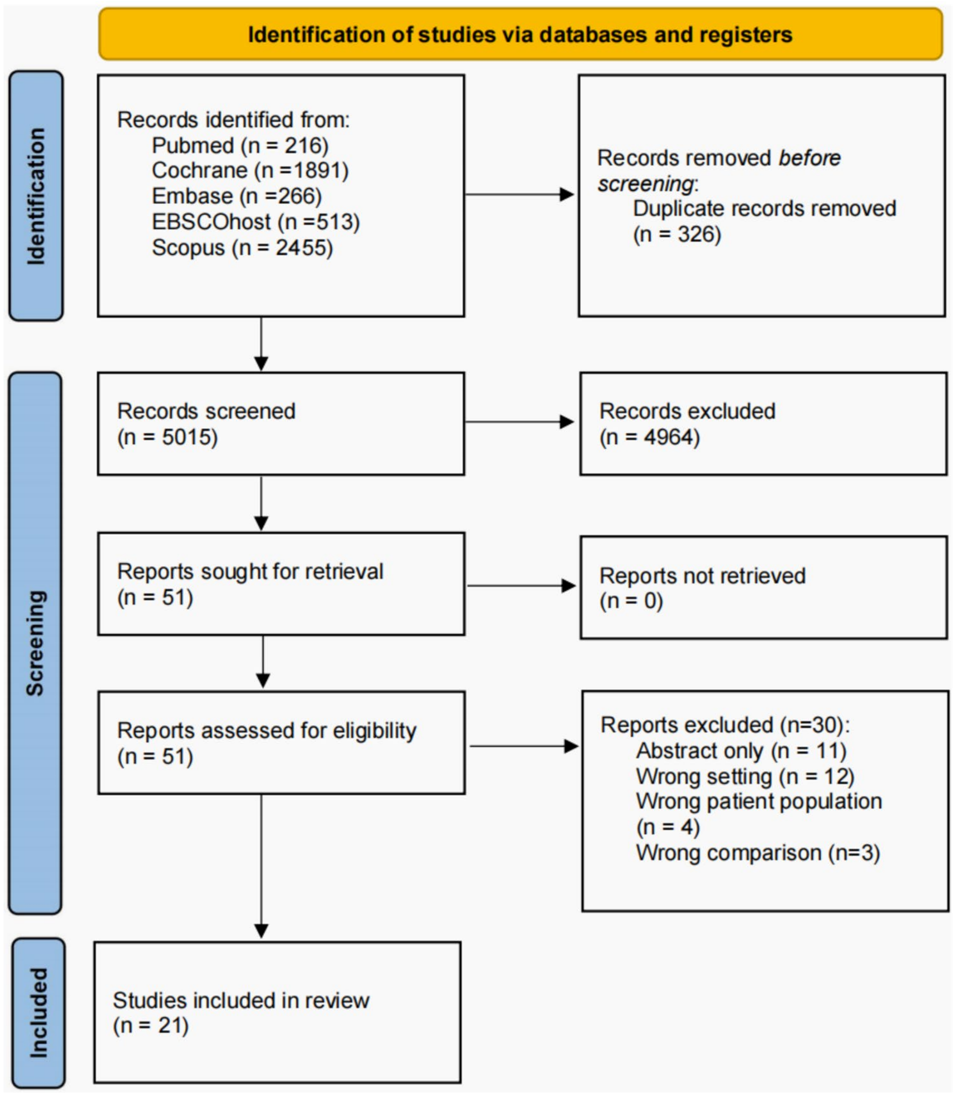

Fig. 1 Flow chart

42]. In one study, different movement representation techniques (mental practice and mirror therapy) were used in two parallel groups, so the data from the two experimental groups were combined for comparison with those from the control group [42].

Experimental interventions

Among the 21 studies, the experimental protocol varied in approach, delivery form, dosage and start time after surgery. Graded motor imagery was used in two studies[9, 41], motor imagery was used in seven studies [24–28, 34, 37], action observation was used in three studies [29, 30, 43], and motor imagery was combined with action observation in two studies [39, 40]. Mirror therapy was adopted in seven studies [31–33, 35, 36, 38, 42]. The form of motor imagery was explicit motor imagery in all nine trials, while graded motor imagery combined both implicit (left-and-right discrimination) and explicit motor imagery. The intervention schedules varied from 2 sessions to 24 sessions. The program duration ranged from 2 days to 12 weeks. With respect to the intervention timing, thirteen studies initiated the experimental intervention within 2 weeks after surgery or during the immobilization period [9, 24, 25, 27–29, 31, 32, 34, 37–39, 43], four studies evaluated the effect of movement representation techniques between the middle and late postoperative periods [26, 33, 35, 41], one study implemented motor imagery before surgery [40], and three studies did not explicitly describe the timing of the intervention ([30, 36, 42].

Comparator intervention

Comparator interventions also varied among the studies. The participants in the control group usually received

Table 1 Study characteristic

Study	Country	Type of surgery	Number of subjects in each group (experimental group/ control group)	Age (experimental group/ control group)	Gender (experimental group/ control group)
Abolfazli 2019	Iran	individuals with hand reconstructive surgery (during the first week after surgery)	20/20	30.45 (9.38) / 33.3 (11.46)	13 male / 7 female; 12 male / 8 female
Bellelli, 2010	Italy	individuals after total hip / knee arthroplasy and hip fracture surgeries (between three to ten days after surgery)	30/30	71.9 ± 8.4 / 71.8 ± 6.9	9 male / 21 female; 14 male/ 16 female
Birinci 2022	Turkey	individuals with post-traumatic elbow stiffness (4 to 8 weeks post-surgery)	25/25	42.1 ± 11.2 / 41.7 ± 10.5	17 male / 8 female; 15 male/ 10 female
Briones-Cantero 2020	Spain	individuals after total knee arthroplasty (24 h after surgery)	12/12	73 ± 5 / 72 ± 6	8 male / 4 female 7 male/ 5 female
Candiri 2023	Turkey	individuals early after total knee arthroplasty (24–48 h after surgery)	9/9	64.77 ± 4.52 / 67.22 ± 6.61	1 male / 8 female 1 male / 8 female
CiviKaraaslan 2020	Turkey	individuals with carpal tunnel syndrome surgery	18/17	48.2 ± 9.7 / 53.1 ± 8.1	2 male / 16 female 1 male / 16 female
Korbus, 2022	Germany	women aged 60 years and older with a distal radius fracture	20/9	75.4 ± 7.24 / 72.4 ± 6.78	All female
Lebon, 2012	France	individuals after anterior cruciate ligament reconstruction surgery (stated7-12 days after the surgery)	7/5	28.5 ± 5.0	Total: 10 male / 2 female
Marusic, 2018	Slovenia	individuals after total hip arthroplasty	10/11	64.4 ± 4.1 / 63.1 ± 5.6	8 male / 2 female 6 male / 5 female
Moukarzel 2019	France	individuals after total knee arthroplasty (acute phase)	10/10	69.60 ± 3.25	2 male / 8 female 2 male / 8 female
Moukarzel 2019	Australia	individuals after total knee arthroplasty (chronic phase,6 months after surgery)	12/12	70.25 ± 2.78 / 69.92 ± 2.73	2 male / 10 female 2 male / 10 female
Paravlic 2019	Slovenia	individuals after total knee arthroplasty	17/17	62.2 ± 4.9 / 60.0 ± 5.7	7 male / 6 female 7 male / 6 female
Paravlic 2020	Slovenia	individuals after total knee arthroplasty	13/13	61.6 ± 5.19 / 58.85 ± 5.24	7 male / 6 female 7 male / 6 female
Park, 2014	Korea	individuals after total knee replacement	9/9	72.67 (12.25) / 70.56 (10.98)	NA
Rostami 2013	Iran	hand orthopedic injuries (time since primary surgery usually around seven to eight weeks)	12/13	36 (22–58) / 39 (29–64)	2 male / 10 female 4 male / 7 female
Stenekes 2009	Netherland	patients after flexor tendon injury during immobilization	13/13	36.1 ± 11.3 / 31.1 ± 10.0	9 male / 4 female 8 male / 5 female
Temporiti, 2022	Italy	individuals with end-stage hip osteoarthritis undergoing total hip arthroplasty.	39/40	62.2 (11.2) / 64.6 (8.0)	23 male / 17 female 23 male / 17 female
Toshniwal 2022	India	post ACL reconstruction surgery (2nd day post-surgery)	15/15	33.13 ± 6.988 / 32.4 ± 5.66	9 male / 6 female 10 male / 5 female
Villafañe, 2017	Italy	individuals after total knee replacement (began around 6th to 8th day after surgery)	14/17	70.4 ± 7.5 / 70.1 ± 7.7	7 male / 7 female 3 male / 14 female
Yalcin 2023	Turkey	individuals with hand flexor tendon injuries after primary surgical repair (middle to late postoperative period)	15/15	36.07 ± 14.3 / 38.47 ± 14.84	13 male /2 female 11 male / 4 female
Yun 2019	Korea	individuals after surgery due to mutilated hand injury	15/15	54.8 ± 10.73 / 50.93 ± 7.38	6 male / 9 female 8 male / 7 female

conventional rehabilitation, which included edema control (acute phase after surgery), stretching, active and passive range-of-motion exercise, strengthening training, gait training (lower extremity injuries), activities of daily living and electrotherapy. In two studies, the control groups received immobilization alone [32, 34]. One study introduced relaxation techniques to the control group to achieve the same amount of time as the experimental group [42]. In one study during the preoperative period, only education was applied [40].

Outcome measures

The outcome measures of interest were pain intensity, strength, range of motion, kinesiophobia, functional

Table 2 Intervention characteristic

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Abolfazli 2019	mirror visual feedback (MVF)	$N=20$ MVF and traditional rehabilitation for 30 and 45 min, respectively. Patients placed the uninjured hand in front of the mirror and the injured hand behind it, and performed simple exercises such as displacement of the Purdue Pegboard pins in various sizes, resistance exercises, and functional exercises including writing and the use of spoons. 75 min/ session, twice a week for 8 weeks	$N=20$ Traditional rehabilitation included scar massage, edema control, controlled active exercises in the range of allowed motions, muscle strengthening, and graded stretching exercises, as well as electrotherapy. 75 min/ session, twice a week for 8 weeks	McGill pain questionnaire, Disability of Arm, Shoulder, and Hand (DASH) scores, range of motion, the strength of grip and pinch, Minnesota Manual Muscle test.	Pre-treatment, 6th week, 8th week, 12th week	The results indicated that both traditional and MVF methods induced significant decreasing pain, disability and increasing dexterity, and range of motion. The results also showed that the positive effect of MVF on pain, disability, dexterity, and range of motion was significantly greater than that of controls, but there was no significant result in grip and lateral pinch strength between the intervention and control group
Bellelli, 2010	Action observation	$N=30$ action observation: watching movies of activities of daily living and execute activities 24 min a day, 6 days a week for 3 weeks +standard rehabilitation protocol: warm-up, range-of-motion exercise and strengthening exercise, transfer practice, balance and gait training one hour a day, 6 days a week for 3 weeks	$N=30$ watching movies of geographic videos + standard rehabilitation protocol one hour a day, 6 days a week for 3 weeks	Functional Independence Measure (FIM), the motor sub-score of FIM, the Tinetti scale, and the dependence on walking assistive	before and after treatment	the experimental group showed significant improvement of FIM total score, the motor sub-score of FIM and Tinetti score compared with the control group
Birinci 2022	graded motor imagery (GMI)	$N=25$ The GMI group received a program consisting of left-right discrimination, motor imagery (imagine the affected side doing functional activities such as washing face and drinking water), and mirror therapy. twice a week for 6 weeks.	$N=25$ The structured exercise (SE) group received a program consisting of range-of-motion, stretching, and strengthening exercises. twice a week for 6 weeks.	Primary outcome: the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire. Secondary outcomes: active range of motion (AROM), visual analog scale (VAS), Tampa Scale for Kinesiophobia (TSK), muscle strength of elbow flexors and extensors, grip strength, left-right discrimination, and Global Rating of Change.	Patients were assessed at baseline, at the end of treatment (12 sessions), and a 6-week follow-up.	Both GMI and SE interventions significantly improved outcomes. After a 6-week intervention, the DASH score was significantly improved in the GMI group compared with the SE group, and improvement continued at the 6-week follow-up. The results with a medium to large effect size were also significant for elbow flexion AROM, elbow extension AROM, VAS-activity, TSK, and muscle strength of elbow flexors and elbow extensors in favor of the GMI group.

Table 2 (continued)

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Briones-Cantero 2020	Motor imagery	*N* = 12 Physical therapy with motor imagery following below principal: (1) observe the exercise of the unaffected limb (2) imagine the exercise of the affected limb (3) imagine the exercise of affected limb with maximum range and no pain (4) execute the exercise 30 min x 5 sessions (in total)	*N* = 12 Physical therapy alone 30 min x 5 sessions (in total)	Primary outcome: short-form Western Ontario McMaster Universities Osteoarthritis Index (WOMAC); Secondary outcome: Visual analog scale, pressure pain thresholds (PPTs), and knee range of motion	Before and after the treatment	Patients in the experimental group showed significant improvement of VAS and WOMAC scores. No significant differences of knee range of motion and PPT were found between groups.
Candiri 2023	graded motor imagery (GMI)	*N* = 9 Graded motor imagery: (1) left-right discrimination: Recognise™ Knee application, 60 images (2) motor imagery: imagine full range of motion and activity of daily life (3) mirror therapy: mirror box and portable mirror + Traditional rehabilitation 3 sessions a week for 6 weeks (each stage for 2 weeks)	*N* = 9 Traditional rehabilitation: ankle-pumping exercises, range of motion exercise, strengthening training and activities of daily living. 3 sessions a week for 6 weeks	Primary outcomes: visual analogue scale and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Secondary outcomes: knee range of motion, muscle strength, the timed up and go test, mental chronometer, Movement Imagery Questionnaire-3, lateralization performance, Central Sensitization Inventory, Pain Catastrophizing Scale, and Tampa Kinesiophobia Scale	Before and 6 weeks after intervention	Activity and resting pain, the Pain Catastrophizing Scale and TKS scores were significantly decreased in GMI group compared with control groups, whereas WOMAC scores, ROM, muscle strength, TUG and Central Sensitization Inventory scores did not show any differences between groups.
CiviKaraaslan 2020	mirror therapy (MT)	*N* = 18 Immobilization period (2 weeks): function-focused exercises using mirror box. 20 min/ session, 10 sessions, 5 days/week, 2 weeks After immobilization period: conventional rehabilitation	*N* = 17 Immobilization period (2 weeks); After immobilization period: conventional rehabilitation	Primary outcome: Boston Carpal Tunnel Syndrome Questionnaire (BCTQ); Secondary outcome: The Nine Hole Peg Test, visual analog scale, the Semmes–Weinstein Monofilament test	One day before surgery, 3rd and 6th weeks after the surgery	The study indicates improvement in the parameters due to the early introduction of MT after CTS surgery, but once conventional methods were started after immobilization, there were no significant differences between groups. However, the MT had reduced pain and improved sensation and function. Both groups experienced positive effects of the surgical treatment and the physiotherapy in the 6th postoperative week.

Table 2 (continued)

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Korbus, 2022	Mental Practice or Mirror Therapy	*N* = 20 mental practice: participants established internal images of the wrist movements; mirror therapy: participant observed the reflection of the non-affected hand in a mirror placed in her midsagittal plane 12 weeks, 24 sessions the first three weeks: 5 sessions per week fourth to sixth weeks: 3 sessions per week sixth to twelfth weeks: self-training	*N* = 9 relaxation techniques to achieve the total amount of time that the therapist spends with the experimental group 12 weeks, 24 sessions	Primary outcome: Patient-rated Wrist Evaluation (PRWE); Secondary outcomes: quickDASH (Disabilities of the Arm, Shoulder and Hand); grip strength; range of motion; health-related quality of life (EQ-5D)	At 0, 3, 6 and 12 weeks	Experimental groups showed higher improvements in terms of PRWE, quickDASH, grip strength and EQ-5D compared to the control group
Lebon, 2012	Motor Imagery	*N* = 7 motor imagery: patients used kinesthetic imagery and were instructed to perceive muscle contractions and joint tension while imagining maximal isometric contraction of a full knee extension. +traditional rehabilitation 45 min per session, 12 sessions, lasted from 28 to 34 days	*N* = 5 traditional rehabilitation included strengthening exercises, massages, passive joint mobilization, electrostimulation, cycling and cryotherapy. 30 min per session, 12 sessions, lasted from 28 to 34 days	Visual Analogue Scale, EMG, Lower Extremity Functional Scale, Anthropometrical Data	pre- and post-intervention	MI elicited greater muscle activation, even though imagery practice did not result in pain decrease.
Marusic, 2018	Action observation and motor imagery	*N* = 10 **hospital session** (4 to 6 days): action observation + motor imagery: locomotor activities (walking with crutches, fast walking, walking upstairs and downstairs, walking on unstable surfaces) + standard physiotherapy, supervised by physical therapist **home sessions**: action observation + motor imagery + standard physiotherapy: supervised by conference vedio calls once a week 30 min per day, 3 times per week fo 8 weeks	*N* = 11 **hospital session** (4 to 6 days): watching documentary videos + standard physiotherapy **home session**: educational documentaries + standard physiotherapy, supervised by conference vedio calls once a week 30 min per day, 3 times per week fo 8 weeks	Timed Up and Go (TUG); Four Step Square Test (FSST); and single- and dual-task gait and postural control	before and 2 months after surgery	the intervention group showed significant better TUG, FSST, and dual-task fast gait, and reduced swing-time variability, and better cognitive performance during dual tasks.

Table 2 (continued)

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Moukarzel 2019	Motor imagery	$N=10$ Motor imagery: 15 min, from first- or third-person perspective, or kinesthetic imagery (such as imagine knee extension and flexion, or eccentric and concentric contraction) +Traditional rehabilitation as per American Physical Therapy Association postoperative guidance: 45 min 1 h x 3 sessions x 4 weeks	$N=10$ Traditional rehabilitation as per American Physical Therapy Association post-operative guidance to reduce pain and knee edema, to enhance knee range of motion and muscle strength, and to improve functional impairments 1 h x 3 sessions x 4 weeks	Visual Analog Scale; active and passive knee range of motion; Quadriceps strength; Timed Up and Go Test; Knee girth	Pre - and post-treatment	Motor imagery group showed significant greater improvement of pain, knee girth, range of motion, quadriceps strength compared to control group.
Moukarzel 2019	Motor imagery	$N=12$ classic physical therapy (45 min) +motor imagery (15 min): internal - and external visual imagery and kinesthetic imagery 3 times per week for 4 weeks starting 6-months after surgery.	$N=12$ classic physical therapy (45 min): progressive lower-extremity strengthening exercises combined with electrical stimulation for quadriceps muscle, manual therapy to improve range of motion, knee proprioceptive exercises, gait training and functional exercises on stairs. + neutral activities (15 min) 3 times per week for 4 weeks starting 6-months after surgery.	quadriceps strength, peak knee flexion during the swing phase, performance at the timed up and go test, stair climbing test, and 6-minute walk test, and Oxford knee score	Pre - and post-treatment	motor imagery enhanced the quadriceps muscle strength of the operated knee, improved the peak knee flexion during the swing phase, and increased the speed to climb and descend stairs
Paravlic 2019	motor imagery	$N=17$ motor imagery in addition to routine physical therapy: maximal voluntary isometric contractions 5 sessions x 4 weeks	$N=17$ routine physical therapy: the exercise program strove to improve patients' general mobility via passive and active knee and hip flexion and extension exercises, muscle strengthening, walking ability and ascending/descending the stairs 5 sessions x 4 weeks	Primary outcome: The maximal isometric knee extension strength of the operated leg. Secondary outcomes: spatial and temporal gait parameters, 30-second chair sit-to-stand performance, Lower Extremity Functional Scale (LEFS) questionnaire, and an MI ability score	before and one month after TKA	the motor imagery group showed less strength decrease, faster self-selected speed under single and dual task conditions; brisk-pace gait speed during single and dual task conditions, improved chair sit-to-stand performance; and a higher score on MI ability questionnaires for kinesthetic imagery (KI) and internal visual imagery (EVI) scales, respectively

Table 2 (continued)

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Paravlic 2020	Hospital- and home-based maximal voluntary isometric contraction imagery	*N* = 13 **Hospitalization period**: Under the seat, imagine the maximum isometric active contraction with 60° knee flexion while listening to PT or tape for guidance. They also received conventional rehabilitation. **+ discharge period**: maximal voluntary isometric contraction imagery with phone call to check the adherence and prescribe exercise program 5 sessions x 4 weeks	*N* = 13 **Hospitalization period**: functional exercise-based rehabilitation program for improving knee range of motion, increasing knee and hip muscle strength, and acquiring functional strategies for activities of daily living. **+ discharge period**: same exercises as those performed in the hospital with phone call the check adherence and prescribe exercise program 5 sessions x 4 weeks	Primary outcome: quadricep muscle strength; voluntary muscle activation. Secondary outcomes: timed up and go test; knee active range of motion; maximal grip strength; the Oxford Knee Score (OKS) questionnaire	1 day prior to surgery and 1 month post-surgery	the experimental group showed lower strength decrease and performed better in TUG and OKS scores. there were no significant differences in knee range of motion and pain level.
Park, 2014	Action observation	*N* = 9 action observation (10 min): eight kinds of lower extremities' movements + standard physical therapy (30 min): gait training and treadmill three times a week for three weeks	*N* = 9 standard physical therapy (30 min): gait training and treadmill three times a week for three weeks	Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Timed Up and Go (TUG), and Visual analogue scale (VAS)	pre-and post-intervention	patients in the intervention group showed significantly higher improvements in WOMAC and VAS compared to the control group, whereas TUG did not differ between two groups
Rostami 2013	Mirror therapy (MT)	*N* = 12 mirror therapy: range-of-motion exercise, resistive exercise and functional activities using both hands 30 min a day, five days a week for three weeks + clinical rehabilitation 30 min a day, five days a week for three weeks	*N* = 13 clinical rehabilitation: aimed to improve active range of motion, such as tendon gliding exercise, place-and-hold exercise and activities of daily living	Primary outcome: total range of motion of hand; secondary outcomes: Disabilities of Arm, Shoulder and Hand (DASH)	before and after treatment, and three weeks' follow-up	The experimental group showed significantly better improvement of total range of motion and DASH scores compared with the control group, and the gains maintained during follow-up period.
Stenekes 2009	Motor imagery	*N* = 13 Subjects were instructed to perform active flexion and extension movements mentally during the immobilization period 6 weeks	*N* = 13 relative immobilization: first four weeks: passive movement; Fifth to sixth weeks: place-hold exercise 6 weeks	Michigan Hand Outcome Questionnaire (MHQ), visual analog scale (VAS), drawing accuracy and speed, active range of motion, preparation time	preinjury, 6, 7, 8, 10, and 12 weeks postoperatively; strength was recorded only on the last measurement to avoided the chance of rupture.	After the immobilization period, the motor imagery group demonstrated significantly less increase of preparation time than the control group. There was no significant influence of motor imagery on the other tested hand function

Table 2 (continued)

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Temporiti, 2022	Action observation and Motor imagery	$N=39$ Experimental group (AO + MI): observe a 2-min action observation for each task followed by a 1-min motor imagery of the task just observed, whereas no movement execution was requested. 2 sessions, 15 min/ session	$N=40$ Participants received only the preoperative education session without performing any additional preoperative activity.	timed up-and-go test (TUG), the 10-Meter Walk Test (10MWT), the Numeric Pain Rating Scale (NPRS), Tampa Scale of Kinesiophobia (TSK), Harris Hip Score (HHS), Kinaesthetic and Visual Imagery Questionnaire (KVIQ-10)	On the day before and at four days after surgery	No between-group differences were found at baseline. Although TUG and 10MWT worsened in both groups, better TUG was found for AO + MI group at four days. NPRS and TSK improved after surgery without between-group differences.
Toshniwal 2022	Mirror therapy (MT)	$N=15$ conventional physiotherapy along with mirror therapy exercises once in a day, total 6 sessions.	$N=15$ conventional therapy once in a day, total 6 sessions.	VAS, knee range of motion, joint proprioception and Lysholm knee score (joint instability)	pre-intervention (baseline) on the 2nd day post ACL reconstruction surgery and post-intervention on 6th day.	Experimental group showed significant improvements of pain, range of motion, and Lysholm knee score compared with control group, except for joint proprioception
Villafañe, 2017	Action observation	$N=14$ action observation and conventional rehabilitation: before the independent exercise began, the experimental group watched videos regarding exercised being performed 60 min a day, 5 days a week for 2 week	$N=17$ a videos of natural scenes + conventional rehabilitation: mobilization, exercise and transfer practice, strength exercise of lower extremities, ankle pump, Continuous Passive Motion 60 min a day, 5 days a week for 2 week	Visual Analogue Scale, active range of motion, passive range of motion, Barthel index, Cumulative Illness Rating Scale, Short Form-36 Health Survey, Tinetti scale.	before and after treatment	the active range of motion was significantly higher in the experimental group compared with the control group
Yalcin 2023	Mirror therapy (MT)	$N=15$ mirror therapy in addition to physical therapy: flexor tendon gliding, blocking exercises, joint ROM and resistance exercises were applied to the healthy hand with a mirror. The patient was asked to look at their hand in the mirror and try to make the same movements with the affected side while watching the movements of the unaffected side in the mirror 12 sessions, 4 weeks	$N=15$ physical therapy: whirlpool, ultrasound, transcutaneous electrical nerve stimulation (TENS) 12 sessions, 4 weeks	range of motion, handgrip strength, visual analog scale (VAS), Patient-Rated Wrist Evaluation (PRWE), Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, Hand Functional Index (HFI), Purdue Pegboard Model, and Tampa Kinesiophobia Scale	before and after treatment	More improvement was observed in the mirror therapy group in terms of visual analog scale, Patient-Rated Wrist Evaluation, Hand Function Index and Disabilities of the Arm, Shoulder and Hand scores. There was no significant difference between groups for the other parameters

Table 2 (continued)

Study	Motor imagery Type	Intervention	Comparison	Outcome measures	Assessment time points	Main findings
Yun 2019	Mirror therapy (MT)	$N=15$ MT and conventional physical therapy after each MT session; 60 min a day, 3 days a week for 4 weeks	$N=15$ conventional physical therapy consisted of whirlpool, transcutaneous electrical nerve stimulation, range of motion exercise 30 min a day, 3 days a week for 4 weeks	Muscle elasticity, visual analogue scale, Korean version of Patient-rated Wrist Evaluation (PRWE)	pre- and post-treatment	There were significant differences in pain and hand function within each group (pre-intervention vs. post-intervention) and between groups (experimental vs. control). However, there was no significant difference in muscle elasticity between groups.

Table 3 Summary of movement representation techniques

Movement representation techniques	Description
Mirror therapy	Participants sit in front of the mirror and observe the reflection of the intact limb
Action observation	Participants watch actions performed by others through video
Motor imagery	Participants mentally recall various activities without actual execution
Graded motor imagery	It consists of three sequential strategies: left-and-right discrimination (phase one), motor imagery (phase two), and mirror therapy (phase three).

scales and functional tests. Pain intensity was a primary outcome in most studies and was evaluated with a visual analog scale and McGill pain questionnaire. Kinesiophobia was assessed by the Tampa Scale for Kinesiophobia. Functional performance referred to both functional scales and functional tests. The functional scales included the Patient-Rated Wrist Evaluation, Disability of the Arm, Shoulder, and Hand (DASH) scores, the Boston Carpal Tunnel Syndrome Questionnaire, the Oxford Knee Score questionnaire, the Lower Extremity Functional Scale, the Western Ontario and McMaster Universities Osteoarthritis Index and the motor subscale of the Functional Independence Measure. The following functional tests were used: the 9-Hole Peg Test, the Purdue Pegboard Test, the Minnesota Manual Dexterity Test (turning test), the timed up-and-go test, the Stair Climbing Test, the Chair Sit-to-stand test, and the response time of left-right discrimination.

Quality assessment

Table 4 summarizes the PEDro scale scores. The mean PEDro score was 6.52, with sixteen trials scored as good quality and five as fair quality. All trials yielded scores between 5 and 9. Owing to the nature of the study design, most trials were unable to blind subjects and therapies who received the intervention. More than half of the studies also failed with allocation concealment and blinding assessors. All trials were comparable at baseline and reported between-group comparisons. Most trials (20 of 21) reported both point and variability measures. More than half of the trials achieved an adequate retention rate and were included in the intention-to-treat analysis.

Effects of interventions and meta-analyses

The levels of evidence regarding different outcome measures were presented in Table 5.

Pain intensity

Thirteen trials reporting data for 423 individuals assessed pain intensity. The meta-analysis revealed that the experimental group experienced significantly lower pain intensity postintervention (SMD=-0.85; 95% CI=-1.26, -0.43; $p<0.001$; moderate-quality evidence), and the heterogeneity was $I^2=74\%$. Figure 2 showed detailed forest plots. Egger's test revealed no publication bias ($p=0.33$) and funnel plot was summarized in supplementary material Fig. 1.

Functional scales

Fourteen trials reported data for 427 individuals and assessed functional scales. The meta-analysis revealed that the experimental group achieved greater improvement in functional scale scores than the control groups did (SMD=-0.84, 95% CI=-1.27, -0.41; $p<0.001$; low-quality evidence), and the heterogeneity was $I^2=76\%$. Figure 3 showed detailed forest plots. Egger's test revealed no publication bias ($p=0.12$) and funnel plot was summarized in supplementary material Fig. 1.

Functional tests

Twelve trials reported data for 374 individuals and assessed functional tests. The meta-analysis revealed that the experimental group had better functional test results in different tasks (SMD=-0.8, 95% CI=-1.01, -0.58, $p<0.001$; very low-quality evidence), and the heterogeneity was $I^2=44\%$. Figure 4 showed detailed forest plots.

Table 4 Physiotherapy evidence database score of the enrolled studies

	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Blind subjects	Blind therapists	Blind assessors	Adequate follow-up	Intention-to-treat analysis	Between-group comparison	Point measure and variability	total score
Abolfazli 2019 [31]	Y	1	1	1	0	0	0	1	1	1	1	7
Birinci 2022 [41]	Y	1	1	1	1	0	1	1	1	1	1	9
Briones-Cantero 2020 [24]	N	1	1	1	0	0	1	1	1	1	1	8
Candiri 2023 [9]	Y	1	0	1	0	0	0	1	0	1	1	5
Civi Karaaslan 2020 [32]	Y	1	0	0	0	0	1	1	0	1	1	5
Korbus 2022 [42]	Y	1	1	1	0	0	1	1	0	1	1	7
Lebon 2012 [37]	Y	1	0	1	0	0	0	1	1	1	1	6
Moukarzel 2019 [26]	N	1	0	1	0	0	0	1	1	1	1	6
Moukarzel 2019 [25]	Y	1	0	1	0	1	1	1	1	1	1	8
Paravlic 2020 [27]	Y	1	0	1	0	0	0	0	1	1	1	5
Paravlic 2019 [28]	Y	1	0	1	0	1	0	1	1	1	1	7
Stenekes 2009 [34]	Y	1	0	1	0	0	0	1	1	1	1	6
Temporiti 2022 [40]	Y	1	1	1	0	1	1	1	0	1	1	8
Toshniwal 2022 [38]	Y	1	1	1	1	0	0	0	0	1	1	6
Yalcin 2023 [35]	Y	1	0	1	0	0	0	1	1	1	1	6
Yun 2019 [36]	Y	1	1	1	0	0	1	1	1	1	1	8
Villafañe 2017 [43]	Y	1	1	1	0	0	1	1	1	1	1	8
Marusic 2018 [39]	Y	1	0	1	0	0	0	0	0	1	1	4
Bellelli 2010 [29]	Y	1	0	1	0	0	1	1	1	1	1	7
Park 2014 [30]	Y	1	0	1	0	0	0	1	1	1	0	5
Rostami 2013 [33]	Y	1	0	1	1	0	1	0	0	1	1	6

Table 5 GRADE for quality of evidence

Outcome measures	Studies (participants)	inconsistency (I2 > 50%)	riks of bias (> 25% of the participants were from studies' PEDro < 6)	imprecision (pooled sample size < 400)	indirectness	publication bias	SMD with 95% CI	quality
pain	13(423)	Yes ($I^2 = 74\%$)	no	no	no	no	-0.85 (-1.26, -0.43)	moderate
functional scales	14(427)	Yes ($I^2 = 76\%$)	no	no	yes	no	-0.84 (-1.27, -0.41)	low
functional tests	12(374)	No ($I^2 = 44\%$)	yes	yes	yes	no	-0.80 (-1.01, -0.58)	very low
range of motion	11(303)	Yes ($I^2 = 79\%$)	no	yes	no	no	0.80 (0.24, 1.35)	low

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Abolfazli, 2019	3.3	3.53	20	9.75	5.42	20	8.3%	-1.38 [-2.08, -0.69]
Birinci, 2022	1.1	0.2	25	1.8	0.4	25	8.2%	-2.18 [-2.89, -1.47]
Briones-Cantero, 2020	30	14.5	12	39.5	19	12	7.6%	-0.54 [-1.36, 0.27]
Candiri, 2023	1	0.85	9	2.6	0.78	9	5.9%	-1.87 [-3.02, -0.71]
CiviKaraaslan, 2020	0.49	0.94	18	0.91	1.73	17	8.5%	-0.30 [-0.96, 0.37]
Lebon, 2012	0.21	0.39	7	1.2	1.25	5	5.4%	-1.08 [-2.34, 0.18]
Paravlic, 2020	31.54	12.14	13	37.13	14.67	13	7.9%	-0.40 [-1.18, 0.38]
Park, 2014	3.11	1.09	9	4.44	0.73	9	6.4%	-1.37 [-2.42, -0.31]
Temporiti, 2022	2.6	2.2	39	2.5	2.2	40	9.6%	0.05 [-0.40, 0.49]
Toshniwal, 2022	2.26	0.45	15	3.2	0.94	15	7.8%	-1.24 [-2.03, -0.45]
Villafañe, 2017	49.6	18	14	47.1	12.96	17	8.2%	0.16 [-0.55, 0.87]
Yalcin, 2023	1.4	1.5	15	3.07	2.81	15	8.1%	-0.72 [-1.46, 0.02]
Yun, 2019	3.62	1.5	15	4.71	1.38	15	8.0%	-0.74 [-1.48, 0.01]
Total (95% CI)			**211**			**212**	**100.0%**	**-0.85 [-1.26, -0.43]**

Heterogeneity: Tau² = 0.42; Chi² = 46.63, df = 12 (P < 0.00001); I² = 74%
Test for overall effect: Z = 3.98 (P < 0.0001)

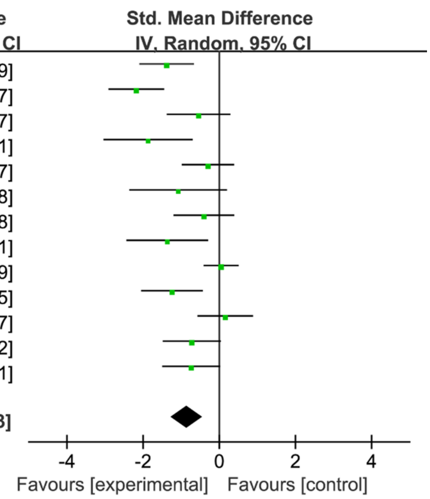

Fig. 2 Forest plot for the standard mean difference in the effect of movement representation techniques on pain intensity

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Abolfazli, 2019	7.56	6.29	20	23.44	11.54	20	7.6%	-1.67 [-2.41, -0.94]
Bellelli, 2010	-22.4	11.9	30	-16	9.3	30	8.5%	-0.59 [-1.11, -0.07]
Birinci, 2022	8.6	2.3	25	18.2	5.2	25	7.5%	-2.35 [-3.08, -1.62]
Briones-Cantero, 2020	9.5	3.5	12	12	4.8	12	7.2%	-0.57 [-1.39, 0.25]
Candiri, 2023	6.7	2.72	9	8.08	2.51	9	6.6%	-0.50 [-1.44, 0.44]
CiviKaraaslan, 2020	3.51	0.47	18	3.24	0.83	17	7.8%	0.39 [-0.28, 1.06]
Korbus, 2022	21.83	13.38	20	28.8	19.7	9	7.3%	-0.44 [-1.23, 0.36]
Lebon, 2012	-49	7.82	7	-48.8	10.7	5	5.8%	-0.02 [-1.17, 1.13]
Moukarzel, 2019 (Dec)	43	1.41	12	42.83	1.46	12	7.2%	0.11 [-0.69, 0.92]
Paravlic, 2019	-34.1	6.8	17	-31.5	8.4	17	7.8%	-0.33 [-1.01, 0.35]
Park, 2014	21.67	2.83	9	29.44	5.83	9	5.9%	-1.61 [-2.71, -0.51]
Rostami, 2013	7	5	12	28	13	11	6.1%	-2.09 [-3.15, -1.04]
Yalcin, 2023	13.92	7.31	15	29.01	16.92	15	7.3%	-1.13 [-1.90, -0.35]
Yun, 2019	61.4	9.25	15	70.03	4.5	15	7.3%	-1.15 [-1.94, -0.37]
Total (95% CI)			**221**			**206**	**100.0%**	**-0.84 [-1.27, -0.41]**

Heterogeneity: Tau² = 0.51; Chi² = 54.94, df = 13 (P < 0.00001); I² = 76%
Test for overall effect: Z = 3.79 (P = 0.0001)

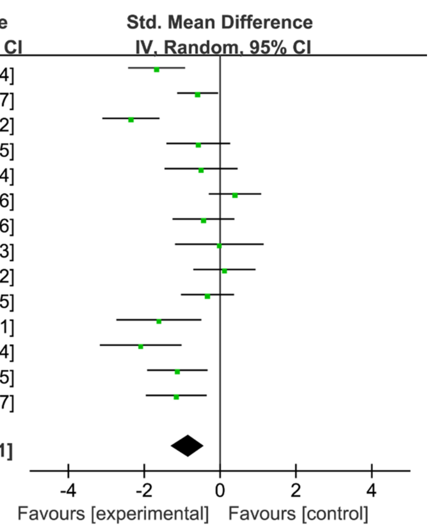

Fig. 3 Forest plot for the standard mean difference in the effects of movement representation techniques on functional scales

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Abolfazli, 2019	91.56	30.33	12	156.4	82.15	11	6.0%	-1.03 [-1.91, -0.15]
Birinci, 2022	2.2	0.4	25	2.5	0.4	25	14.0%	-0.74 [-1.31, -0.16]
Candiri, 2023	11.22	3.21	9	12.66	4.77	9	5.3%	-0.34 [-1.27, 0.59]
CiviKaraaslan, 2020	13.81	2.56	18	14.5	2.63	17	10.4%	-0.26 [-0.93, 0.41]
Marusic, 2018	-3.7	14	10	27.8	37.2	11	5.4%	-1.06 [-1.98, -0.13]
Moukarzel, 2019	12.7	2.76	10	13.32	2.66	10	6.0%	-0.22 [-1.10, 0.66]
Moukarzel, 2019 (Dec)	13.72	0.79	10	14.74	0.93	10	5.0%	-1.13 [-2.09, -0.17]
Paravlic, 2019	-9.2	2.6	17	-5.8	2.7	17	8.4%	-1.25 [-2.00, -0.51]
Paravlic, 2020	7.55	1.22	13	11.54	3.01	13	5.5%	-1.68 [-2.60, -0.77]
Park, 2014	18.11	3.06	9	18.31	4.48	9	5.4%	-0.05 [-0.97, 0.87]
Temporiti, 2022	20.5	12.3	39	26.3	2.3	40	22.5%	-0.65 [-1.11, -0.20]
Yalcin, 2023	-6	6.54	15	5	4.9	15	6.0%	-1.85 [-2.73, -0.98]
Total (95% CI)			**187**			**187**	**100.0%**	**-0.80 [-1.01, -0.58]**

Heterogeneity: Chi² = 19.69, df = 11 (P = 0.05); I² = 44%
Test for overall effect: Z = 7.26 (P < 0.00001)

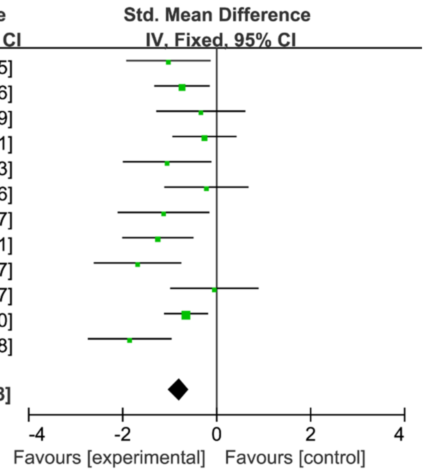

Fig. 4 Forest plot for the standard mean difference in the effect of movement representation techniques of functional tests

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Abolfazli, 2019	160.25	49.38	20	140	43.62	20	10.3%	0.43 [-0.20, 1.05]
Birinci, 2022	128	10.31	25	118	11.29	25	10.4%	0.91 [0.33, 1.50]
Briones-Cantero, 2020	71.5	11.8	12	73.5	10.5	12	9.5%	-0.17 [-0.97, 0.63]
Candiri, 2023	106	1.61	9	104.33	14.45	9	8.9%	0.15 [-0.77, 1.08]
Korbus, 2022	32.12	22.15	20	43.5	46.5	9	9.5%	-0.35 [-1.14, 0.44]
Lebon, 2012	37.86	14.1	7	30	7.91	5	7.7%	0.60 [-0.58, 1.79]
Moukarzel, 2019	111	2.11	10	111	2.11	10	9.1%	0.00 [-0.88, 0.88]
Paravlic, 2020	85.49	10.07	13	78.69	14.99	13	9.6%	0.52 [-0.27, 1.30]
Rostami, 2013	198	36	12	99	18	11	7.0%	3.31 [1.98, 4.64]
Toshniwal, 2022	88.06	4.94	15	71.26	8.68	15	8.8%	2.31 [1.36, 3.27]
Villafañe, 2017	95.7	6.37	14	80.1	10.15	17	9.3%	1.75 [0.91, 2.60]
Total (95% CI)			**157**			**146**	**100.0%**	**0.80 [0.24, 1.35]**

Heterogeneity: Tau² = 0.68; Chi² = 48.26, df = 10 (P < 0.00001); I² = 79%
Test for overall effect: Z = 2.81 (P = 0.005)

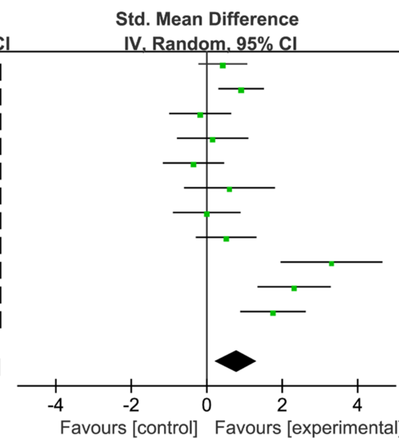

Fig. 5 Forest plot for the standard mean difference in the effect of movement representation techniques on range of motion

Egger's test revealed no publication bias ($p = 0.94$) and funnel plot was summarized in supplementary material Fig. 1.

Range of motion

Eleven trials reported data for 303 individuals and assessed their range of motion. The meta-analysis revealed that the experimental group had a greater range of motion than did the control group (SMD = 0.8, 95% CI 0.24, 1.35, $p = 0.005$; low-quality evidence), and the heterogeneity was $I^2 = 79\%$. Figure 5 showed detailed forest plots. Egger's test revealed no publication bias ($p = 0.14$) and funnel plot was summarized in supplementary material Fig. 1.

Muscle strength

Nine trials reported muscle strength data for 247 individuals. The meta-analysis revealed no significant effect on muscle strength (SMD = 0.33, 95% CI=-0.08, 0.74, $p = 0.11$), and the heterogeneity was $I^2 = 59\%$. Figure 6 shows detailed forest plots. Egger's test revealed no publication bias ($p = 0.97$).

Kinesiophobia

Four trials pooled the results of the Tampa scale for kinesiophobia in 177 individuals. No significant differences were observed between the groups after the intervention (MD=-3.19, 95% CI=-9.01, 2.63, $p = 0.28$). The heterogeneity was $I^2 = 88\%$. Figure 7 shows detailed forest plots. Egger's test revealed no publication bias ($p = 0.45$).

Subgroup analysis

To explore the source of heterogeneity, we conducted subgroup analyses regarding pain intensity, functional scale scores and range of motion. Intervention quantity was the cause of heterogeneity in pain intensity. In the single intervention group, I^2 significantly decreased to 40%, whereas the p value remained significant. The DASH scale was the cause of heterogeneity in the functional scales. After distinguishing DASH from other scales as outcome measures, the I^2 of both subgroups

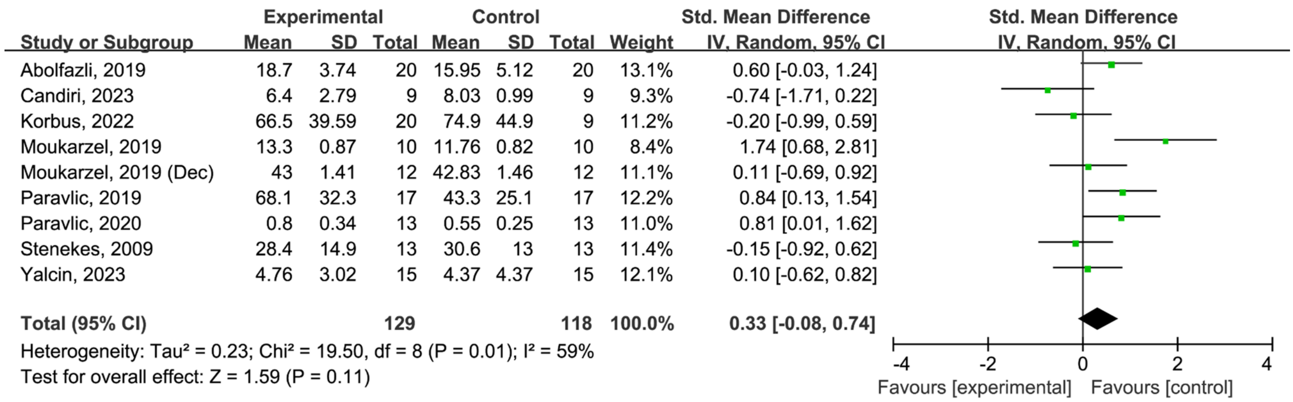

Fig. 6 Forest plot for the standard mean difference in the effect of movement representation technique on muscle strength

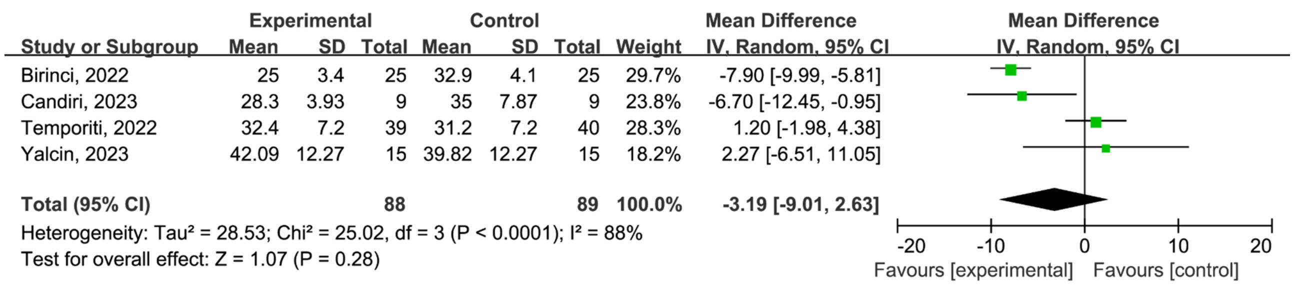

Fig. 7 Forest plot for the mean difference in the effects of movement representation techniques on fear of movement

decreased to 45%, and the *p* value remained significant. Intervention content was an influencing factor for range of motion. The mirror therapy group presented high heterogeneity, whereas the other group presented I^2 values lower than 50%. The details and forest plots of the subgroup analysis are presented in Fig. 8.

Discussion

In this systematic review, a total of 21 trials with 659 postsurgical individuals were included. Four types of movement representation techniques, including mirror therapy, motor imagery, graded motor imagery and action observation, were used. Only individuals who underwent orthopaedic surgeries, such as joint replacement surgery, hand reconstruction or tendon repair surgery, anterior cruciate ligament reconstruction surgery, distal radius fracture surgery, posttraumatic elbow stiffness, and carpal tunnel syndrome surgery, were enrolled. In our study, evidence ranging from moderate to very low quality suggested that, compared with conventional rehabilitation alone, movement representation techniques significantly improved pain intensity, functional scales, functional tests, and range of motion. However, the evidence for muscle strength and fear of movement remains uncertain, considering the relatively small sample size with respect to kinesiophobia. The results from the meta-analysis provided preliminary evidence for the effectiveness of movement representation techniques for pain relief, functional performance, range of motion, muscle strength and fear of movement in individuals after orthopaedic surgeries.

It was difficult to provide a standard clinical protocol regarding the use of movement representation techniques in orthopaedic individuals on the basis of our results because of the diversity of intervention durations, frequencies, timings and types. Although we managed to explain the cause of heterogeneity (such as intervention content and outcome measures), there may be other potential factors. For example, pharmacological treatment or modalities were also administrated differently across studies. Although such treatments were always used both in experimental and control groups, cautious should be taken for future studies to consider such potential confounding factors. Previous studies have tested the dose–response effects of motor imagery in healthy populations. Paravlic et al. [28] reported that a training duration of four weeks with a frequency of three times per week could yield satisfactory improvement. In terms of the training period for postsurgical individuals, 13 trials conducted interventions over four weeks, seven trials conducted less than four weeks, and one trial performed motor imagery as preoperative education for two sessions. In terms of training frequency, consistent with previous studies, more than half of the included studies reported training frequency of three times a week.

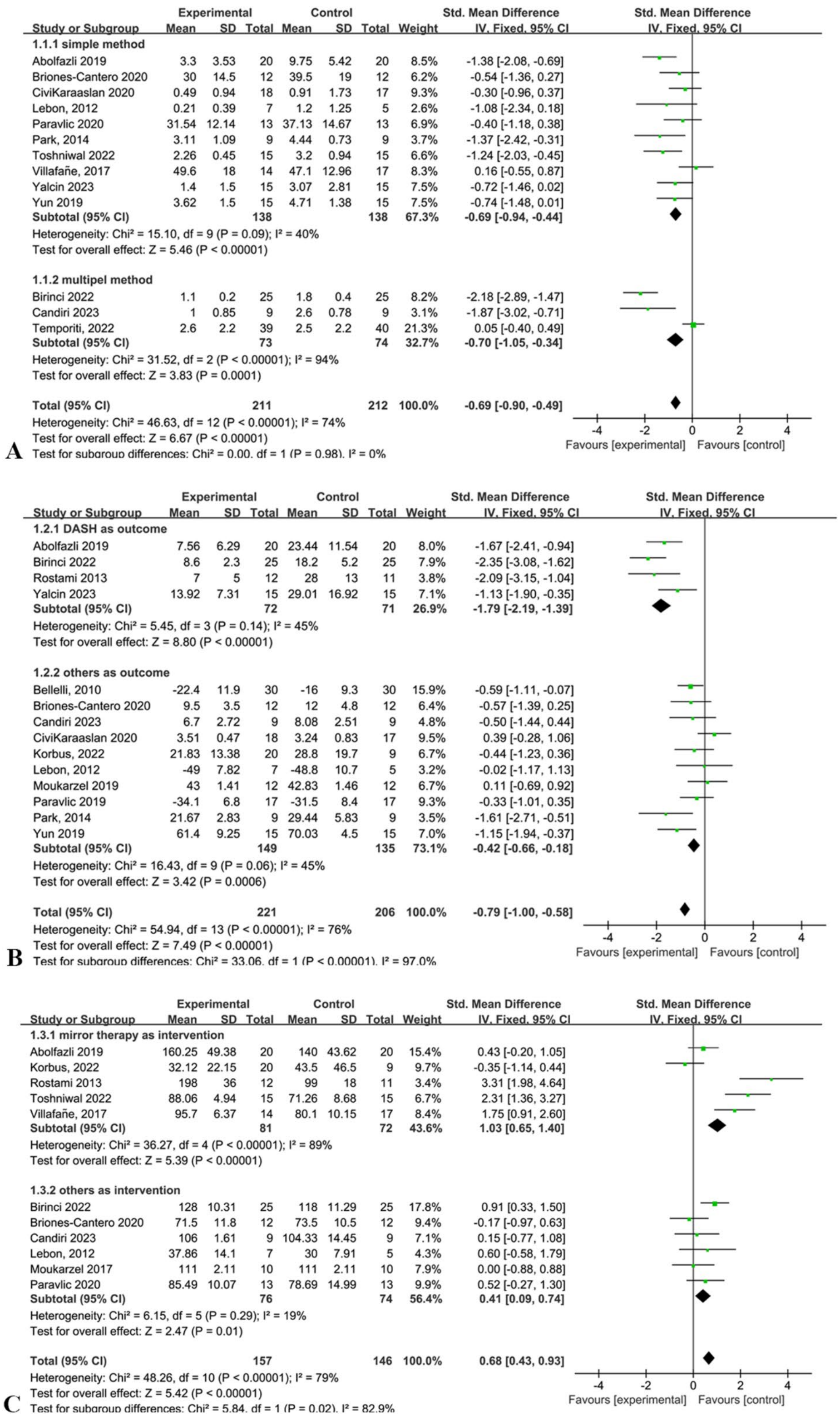

Fig. 8 Subgroup analysis of pain intensity (**A**), functional scale score (**B**), and range of motion (**C**)

Studies have suggested that different types of motor imagery may involve distinct underlying neural structures [44]. Explicit motor imagery referred to conscious motor imagery, which was assessed via self-reported scales such as kinesthetic and visual imagery questionnaires. Implicit motor imagery refers to unconscious motor imagery, which is always assessed with a hand laterality judgment task [45]. Caution should be taken when one tool is used to monitor and screen individuals [46]. In our study, motor imagery in all eight trials was explicit motor imagery, and graded motor imagery included both explicit and implicit motor imagery. According to our results, explicit motor imagery was more widely adopted for individuals after orthopaedic surgeries and was able to yield satisfying results.

The mechanism of movement representation techniques has been widely investigated. Individuals who undergo orthopaedic surgeries always exhibit high irritability and inflammatory responses, which prevent them from moving. Individuals with osteoarthritis before surgery also experience decreased activation of related cortical representation areas or impaired central nervous system processing [10, 47]. Studies have shown that motor imagery enhances the functional activity of premotor, somatosensory and parietal networks in the same way as actual motor execution does [48, 49]. The premotor region mainly includes the ventral premotor cortex, dorsal premotor cortex and presupplementary area, which contain mirror neurons and contribute to action preparation [49]. Mirror neurons were essential neural substrate for understanding and executing movement. The activation of mirror neurons or mirror neuron-based therapy have been proved to improve functional performance [50, 51]. The parietal cortex is also believed to contain mirror neurons and is usually responsible for the processing of multiple types of sensory information [49]. The consistent recruitment of the somatosensory cortex implies the kinesthetic aspects of movement representation techniques [52]. The subcortical structures, such as the cerebellum and putamen, are also involved in actual movement and present plasticity changes during motor imagery and action observation. In our study, we found that movement representation techniques were significantly more effective than conventional rehabilitation alone in terms of functional tests and functional scales. This functional improvement may be correlated with increased recruitment of the functional representation cortex, and the specific mechanism in postorthopaedic individuals should be further investigated. Furthermore, except for orthopaedic rehabilitation, movement representation techniques were also beneficial for improving motor function and balance in patients with Parkinsons's disease [51]. It highlighted the boarder application of movement representation techniques in other rehabilitation area.

Movement representation techniques may also modulate pain through the activation of certain functional representative cortical areas [53]. In addition, motor imagery achieves hypoalgesic effects on individuals by modulating sensory and emotional aspects instead of redirecting participants' attention. For example, when harmful stimuli were presented to participants imagining wearing gloves, not only did the subjective perception of pain decrease, but high-intensity pain was also more frequently categorized as nonnociceptive pain [54]. Furthermore, movement representation techniques could also counteract the reduction in pain-induced corticomotor excitability, especially during acute musculoskeletal pain [55]. Although studies have argued that acute pain due to peripheral factors may be less beneficial from movement representation techniques [14], postsurgical pain tends to be relieved within one week, and most interventions continue for at least four weeks. In such circumstances, peripheral factors are less important to consider. Thus, early activation of the motor execution network could be broadly beneficial for postsurgical individuals.

Enhanced recovery after surgery (ERAS) is a multidisciplinary approach for individuals subjected to orthopaedic surgeries [56, 57]. It was developed to reduce postsurgical complications and stress. A recent systematic review and meta-analysis revealed that in individuals undergoing orthopaedic surgery, ERAS was able to significantly reduce the pain level, complication rate and length of stay [58]. ERAS contains several main elements during perioperative management, such as early mobilization, pain control, minimally invasive surgery, and nutrition and fluid management. Early mobilization is one of the core elements of postoperative ERAS management and has been advocated in nearly all trials involving the ERAS protocol for joint replacement surgeries [59, 60]. It has additional benefits in improving lower extremity function. In our study, more than half of the enrolled trials initiated the interventions within two weeks after surgery, and we found that the experimental group that used movement representation techniques to activate the motor cortex early performed better in the functional test (i.e., the 9-Hole Peg Test, the Purdue Pegboard Test, the Minnesota Manual Dexterity Test, the TUG test, the Stair Climbing Test, and the Chair Sit-to-Stand Test) and in the functional scales (i.e., the PRWE test, DASH test, the BCTQ test, the OKS test, the LEFS test, and the WOMAC). It has been postulated that mental rehearsal could enhance motor preparation to achieve better functional performance [25]. Furthermore, the completion rate of early mobilization has rarely reached 80% [58], especially in elderly adults. Movement representation techniques may therefore be a more suitable approach for individuals, especially for individuals with low physical reserve and mobilization restrictions [61], to quickly activate the task-representative motor cortex.

Limitations

There are several limitations in our study to disclose. First, this study provides preliminary evidence for the use of movement representation techniques in orthopaedic surgeries. However, the dosage and timing of each trial used varied significantly. Most trials initiated the intervention within two weeks after surgery, whereas other trials started in the middle-to-late stage. It was difficult to provide a standard protocol for clinicians on the basis of our study. Future studies should consider establishing standardized protocol based on the following key factors, such as optimal intervention timing, evidence-based recommendations for intervention frequency and duration, types of movement representation techniques based on patient-specific factors and clinical goals. Second, the variability in evidence quality is also a limitation in our study, which was mainly due to heterogeneity between studies and different outcomes used. Future studies should conduct larger, well-designed randomized controlled trials with standardized methodologies to reduce bias and inconsistency. Ensuring more rigorous reporting outcomes and methodologies should also be considered to enhance transparency and reproducibility. Third, some important outcome measures, such as kinesiophobia, lack a sufficient sample size to draw conclusions. Only four trials measured fear of movement, with significant heterogeneity. Fear of movement is an important outcome and could be a potential mechanism influencing functional performance. Recent studies have suggested that the level of functional performance was determined by the individuals' perception of joint and the confident they have when using it [62, 63]. To better understanding the mechanism of movement representation techniques in patient post-orthopaedic surgery, future studies should include kinesiophoia as outcome measures and utilize standardized assessment tool and methodologies for measuring kinesiophobia. Finally, few of the included studies assessed motor imagery ability. This could be a potential confounder to the final conclusion.

Conclusion

There is emerging evidence regarding the application of movement representation techniques for musculoskeletal disorders. This systematic review and meta-analysis supported the use of such techniques in individuals after orthopaedic surgery and revealed significant improvements in pain relief and functional performance, with moderate to very low-quality evidence. Further studies should conduct larger and well-designed randomized controlled trials to establish standard protocol and improve evidence quality. The mechanism of movement representation techniques, such as mirror neuron activation underlying post-orthopaedic or neurological conditions should also be further investigated. Cautious should be taken in future studies to control other confounding factors.

Appendix

Search strategy for PubMed

((((motor imagery[Title/Abstract]) OR (graded motor imagery[Title/Abstract])) OR (action observation[Title/Abstract])) OR (mirror therapy[Title/Abstract])) AND ((randomized controlled trial[Title/Abstract]) OR (randomized controlled study[Title/Abstract]))

Search strategy in Cochrane

#1: (randomized controlled trial): ti, ab, kw OR (randomized controlled study): ti, ab, kw.

#2: (motor imagery): ti, ab, kw OR (graded motor imagery): ti, ab, kw OR (mirror therapy): ti, ab, kw OR (action observation): ti, ab, kw.

#3: #1 and #2.

Search strategy in Embase

#1: 'graded motor imagery':ti, ab, kw OR 'action observation':ti, ab, kw OR 'motor imagery':ti, ab, kw OR 'mirror movement therapy':ti, ab, kw OR 'mirror therapy':ti, ab, kw.

#2: 'randomized controlled trial':ti, ab, kw OR 'randomized controlled study':ti, ab, kw.

#3: #1 AND #2.

Search strategy in EBSCOhost

(graded motor imagery OR action observation OR motor imagery OR mirror movement therapy OR mirror therapy) AND (AB Randomized Controlled Trial OR AB randomized controlled study).

Search strategy in Scopus

((TITLE-ABS-KEY (randomized AND controlled AND trial) OR TITLE-ABS-KEY (randomized AND controlled AND study))) AND ((TITLE-ABS-KEY (graded AND motor AND imagery) OR TITLE-ABS-KEY (action AND observation) OR TITLE-ABS-KEY (motor AND imagery) OR TITLE-ABS-KEY (mirror AND movement AND therapy) OR TITLE-ABS-KEY (mirror AND therapy))).

Abbreviations

PEDro	Physiotherapy Evidence Database
GRADE	Grading of Recommendations Assessment, Development, and Evaluation
DASH	Disability of Arm, Shoulder, and Hand
ERAS	Enhanced recovery after surgery

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-025-08496-0.

Supplementary Material 1

Acknowledgements
Not applicable.

Author contributions
XY, WQZ, XQW, QP, XFG, QH designed the concept. XY, HJW, JXW acquired data. XY, HJW, HJ, XQW, WQZ, QP, XFG, QH interpreted data. XY wrote the first draft of the manuscript, and other authors reviewed the manuscript. All authors approved the final version and submission of the manuscript.

Funding
One author (Wen-qian Zhi) received funding from Beijing Municipal Administration of Hospitals Incubating Program (PX2024018).

Data availability
All data generated or analysed during this study are included in this article and its supplementary material.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 29 December 2024 / Accepted: 4 March 2025
Published online: 18 March 2025

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