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Title Page

Title

A Scoping Review on Motor Imagery-Based Rehabilitation: Potential Working Mechanisms and Clinical Application for Cognitive Function and Depression

Authors

Yule **Hu**, M.S., PhD student[1]; Yan **Li**, PhD[1*]; Angela Yee Man **Leung**, PhD[1]; Jiaying **Li**, M.S., PhD student[1]; Xiaoxiao **Mei**, M.S., PhD student[1]; Jed **Montayre**, PhD[1]; Ran **Tao**, PhD[2]; Janelle **Yorke**, PhD[1]

Affiliations

[1]School of Nursing, The Hong Kong Polytechnic University, Hong Kong, China

[2]Research Centre for Language, Cognition, and Neuroscience, Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University, Hong Kong, China

Corresponding author

*Yan Li, email: yan-nursing.li@polyu.edu.hk

School of Nursing, The Hong Kong Polytechnic University, Hong Kong, China.

Statements and Declarations

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- **Ethical approval and informed consent**

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- **Data availability statement**

Not Applicable.

CRediT authorship contribution statement

Yule Hu and Yan Li were responsible for the conceptualization, methodology, formal analysis and investigation, writing-original draft, and writing-review and editing; Angela Yee Man Leung, Jiaying Li, Xiaoxiao Mei, Jed Montayre, Ran Tao, and Janelle Yorke were responsible for the conceptualization, writing-original draft, and writing-review and editing.

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Abstract

Objective: To map evidence on the characteristics, effectiveness, and potential mechanisms of motor imagery interventions targeting cognitive function and depression in adults with neurological disorders and/or mobility impairments.

Data Sources: Six English databases (The Cochrane Library, PubMed, Embase, Scopus, Web of Sciences, and PsycINFO), two Chinese databases (CNKI and WanFang), and a gray literature database were searched from inception to December 2024.

Review Methods: This scoping review followed the Joanna Briggs Institute Scoping Review methodology. Interventional studies that evaluated motor imagery for cognitive function and/or depression in adults with neurological disorders and/or mobility impairments were included.

Results:A total of twenty-four studies, primarily involving adults with cerebrovascular diseases, multiple sclerosis, and Parkinson's disease, were identified. Motor imagery was typically conducted at home/clinic, occurring 2-3 sessions per week for approximately 2 months, with each session lasting 20-30 minutes. The 62.5% of studies (n=10) reported significant improvements in cognitive function, exhibiting moderate-to-large effect sizes (Cohen's *d*=0.48~3.41), especially in memory, attention, and executive function, while 53.3% (n=8) indicated alleviation in depression with moderate-to-large effect sizes (Cohen's *d*= -0.72~ -2.56). Motor imagery interventions could relieve pain perception and promote beneficial neurological changes in brains by facilitating neurotrophic factor expression and activating neural circuits related to motor, emotional, and cognitive functions.

Conclusion: Motor imagery could feasibly be conducted at home, with promising effects on cognitive function and depression. More high-quality randomized controlled trials and neuroimaging techniques are needed to investigate the effects of motor imagery on neuroplasticity and brain functional reorganization, thereby aiding in the development of mechanism-driven interventions.

Keywords: Motor imagery; Neurological disorder; Mobility impairment; Cognitive impairment; Depression

Clinical Messages:

- Motor imagery can be conducted at home as a preventive and interventional therapy for cognitive function and depression in adults with neurological disorders and/or mobility impairments but not severe cognitive impairments.
- Motor imagery was typically performed 2-3 sessions weekly for an average of 2 months, with each session lasting 20-30 minutes.

Introduction

Cognitive impairment and depression are two common disorders among adults with neurological disorders and/or mobility impairments that have a negative impact on the treatment and rehabilitation process, subsequently affecting social reintegration, leisure activities, and overall quality of life [1]. Emerging evidence indicates that cognitive impairment frequently co-occurs with depression, and these two disorders can be mutually prompted [2, 3]. The Lancet Commission report also indicated a bidirectional causal association between these two conditions [4]. Cognitive impairment, particularly in attention, could act as a gateway for negative thoughts and biases and is one of the internal stressors maintaining the depressive state [5]. The negative emotional state could influence cognitive functions such as information processing and reasoning [5].

There is increasing interest in non-pharmacologic therapies for improving cognitive function and alleviating depression in adults with neurological disorders and/or mobility impairments. Notably, the positive effects of physical exercise on both conditions have been demonstrated [6, 7]. However, physical exercise is only suitable for individuals with certain levels of motor functions and may be impractical or ineffective for those with severe physical disabilities, troublesome pain states, or muscle paralysis [8]. Furthermore, safe and effective exercise prescription and progress monitoring typically require substantial healthcare resources. In contrast, motor imagery presents a promising therapy that can address these limitations. Motor imagery is a mental simulation process that entails the systematic use of imagery to covertly rehearse a movement without actually executing it [9]. This process involves the internal simulation of actual exercise, thereby inducing neural and autonomic changes similar to those executing real exercise [10, 11]. Motor imagery, in particular, enables individuals who are unable to perform regular physical exercise to start the rehabilitation process in a safer and less provocative way [12]. Furthermore, motor imagery techniques can be self-administered with appropriate training and represent a cost-effective, safe, and flexible approach [13].

As a non-invasive therapy, motor imagery has proven effective in enhancing physical function, particularly among adults with neurological disorders and/or mobility impairments [14]. In recent years, it has gained traction as a promising neurorehabilitation approach for improving cognitive function and alleviating depression in this population [15]. Motor imagery has been demonstrated to enhance functional connectivity and neuroplasticity in the brain, which are essential for cognitive function and emotional processing [15]. However, the evidence on this therapy for cognitive function and depression exhibits considerable variability, particularly regarding the design, implementation, effectiveness, and underlying mechanisms. Previous reviews primarily addressed motor imagery in pain relief [16-18], physical function [18-20], and movement outcomes [21]. There remains a gap in the provision of comprehensive, evidence-based guidance for future motor imagery intervention development to improve cognitive function and depression. Therefore, this scoping review aims to address this gap by comprehensively mapping the existing motor imagery interventions that target cognitive function and depression in adults with neurological disorders and/or mobility impairments. This will serve as the foundation to support the design of more effective, evidence-based interventions and enhance clinical utility. The four review questions that were used to guide this study were as follows:

1. What are the characteristics of the targeted population?
2. What are the components and delivery methods of the motor imagery interventions?
3. What are the reported feasibility and acceptability of these interventions?
4. What are the effectiveness and potential mechanisms underlying motor imagery interventions for cognitive function and depression?

Methods

This scoping review adhered to the methodological guidance of the Joanna Briggs Institute's (JBI) Manual for Evidence Synthesis [22] and was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis Extension for Scoping Reviews (PRISMA-ScR) guidelines and checklist [23]. It was registered in the Open Science Frame (OSF) (http://osf.io/9pckq). There was no need for ethical approval or informed consent since this is a review research.

Eligibility criteria

The eligibility criteria were developed in accordance with the Population, Concept, Context, and Sources and Types of Evidence framework, which is recommended by the JBI Manual for scoping reviews [22].

Population

The population in this scoping review consisted of adults (≥18 years old) with neurological disorders and/or mobility impairments. No restrictions were placed on other demographic characteristics (e.g., gender, ethnicity, or education level).

Concept and context

One of the core concepts of this scoping review is classical motor imagery. Eligible studies should adopt classical motor imagery interventions, in which participants mentally visualize movements without using external devices to interpret or transform brain signals [24]. The other core concepts were the intervention outcomes, including global cognitive function and/or specific cognitive domains (executive function, complex attention, learning and memory, language, perceptual-motor function, and social cognition) based on the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [25], and/or depression. No restrictions were placed on the study setting or residence.

Information sources

The information sources of this review included six English electronic databases (The Cochrane Library, PubMed, Embase, Scopus, Web of Sciences, and PsycINFO), two Chinese databases (China National Knowledge Infrastructure and WanFang), a gray literature database (ProQuest Dissertations & Theses), and reference lists of included studies.

Types of publications

The types of studies were intervention studies, which include randomized controlled trials (RCTs), cross-over studies, non-randomized controlled trials, quasi-experimental, before and after studies, and case studies. We excluded letters, protocols, reviews, conference abstracts, and studies with no full text available. Only studies published in English or Chinese were considered.

Study search and selection

The nine databases were systematically searched from inception (their earliest available date) to December 2024. An updated Google Scholar search was conducted right before the submission of the manuscript to identify any potential new studies. The search strategy was developed by using combinations of key terms surrounding motor imagery, cognitive function, and depression (complete search strategies for each database are available in Supplementary Materials). Reference lists of included studies and relevant reviews were manually screened to identify any additional studies. The retrieved studies were imported into literature management software (EndNote 21). And this software was also used to automatically remove duplicate entries.

Two reviewers (YLH and JYL) independently read the titles and abstracts of the remaining studies and evaluated the full texts of potentially eligible papers that met the criteria. Any remaining inconsistencies in decisions after discussion were resolved by consulting a third reviewer (YL).

Quality appraisal

The JBI critical appraisal tools for the assessment of risk of bias for RCTs [26] and quasi-experimental studies [27] were employed by two independent reviewers (YLH and JYL). Any remaining disagreements after the discussion were resolved by consulting a third reviewer (YL). The tools contain the following domains: selection and allocation, administration of intervention/exposure, outcomes assessment, attrition bias, and trial designs. Each item in both tools can be evaluated as met (yes), unmet (no), unclear, or not applicable.

Data extraction

The study characteristics were extracted using a modified version of the data extraction form based on the JBI Manual for Evidence Synthesis [22], including the following information: the first author, publication year, country, study population, exclusion criteria related to the suitability of motor imagery, study design, study setting, intervention and control types, cognitive/depression assessment tools and the results, and the interventions' feasibility and acceptability. The following indicators determine study feasibility: (1) the recruitment rate (i.e., the percentage of participants who gave consent after being determined to be eligible) and (2) the dropout rate (i.e., the number of participants who dropped out after randomization divided by the total number of participants who agreed to consent) [28]. The acceptability indicators include (1) adverse event record associated with motor imagery interventions, (2) participant satisfaction with the interventions, and (3) adherence rate-the percentage of participants who completed the interventions as the researchers defined them [28].

Data on the intervention characteristics, including design, content, delivery features, and intervention fidelity were extracted based on the Template for Intervention Description and Replication (TIDieR) checklist and guide [29]. The elements of motor imagery strategies were extracted based on the typical model, which is denoted by the acronym PETTLEP (Physical, Environment, Task, Timing, Learning, Emotion, Perspective) [30]. The PETTLEP model was created to standardize the design of motor imagery strategies and recommends the minimum checklist of relevant components to be considered to maximize functional equivalence [30]. Functional equivalence refers to the greatest possible stimulation of the same brain areas during motor imagery than during actual, and reinforcement of the memory trace of the corresponding motor task [30]. The design of strategy components and the interactions among these components could affect the level of functional equivalence [10]. Table 1 illustrates the motor imagery strategy terminology based on the PETTLEP model.

Table 1 Motor imagery strategy terminology based on the PETTLEP model [31, 32]

PETTLEP category	Element description and categories
P (Physical)	Refers to the physical state of performer during MI, including aspects such as position and physical sensations.
E (Environment)	Refers to the place where the MI is performed.
T (Task)	Refers to the contents of the MI.
T (Timing)	Refers to the pace at which the MI is completed.
L (Learning)	It emphasizes that the contents of MI should be consistent with the performer's learning progress, which requires regular review and updates.
E (Emotion)	It relates to the fact that actual motor is an emotion-laden experience, and therefore, for imagery to be realistic, the emotions felt during performance should be mentally recreated during imagery practice.
P (Perspective)	Refers to the viewpoint of the performer during imagery. This can be internal/first-person (through the performer's eyes) or external/third-person (observing the action as an onlooker).

PETTLEP: Physical, Environment, Task, Timing, Learning, Emotion, Perspective.

Data synthesis

We performed a narrative synthesis of the included studies to map the literature according to the research questions. The data were presented using descriptive tables and charts and summarized based on inductively developed objectives. We used Cohen's *d* as the index of effect size, where 0.2 denotes a small effect, 0.5 a moderate effect, and 0.8 a large effect. For studies that did not report Cohen's *d*, this metric was calculated by dividing the mean difference between the intervention group and control group after the intervention by the pooled standard deviation [33].

Results

Figure 1 shows the flowchart of study selection. There were 3,384 articles identified through searching the specified databases, gray literature, and manual searches of reference lists. After removing 1,538 duplicates and screening by title and abstract, 215 articles remained. After a full-text review of the remains, 25 articles were finally included in this scoping review. Sarasso et al. reported the same study in two separate articles [34, 35]. These two articles were merged into a single study to prevent duplication in data synthesis.

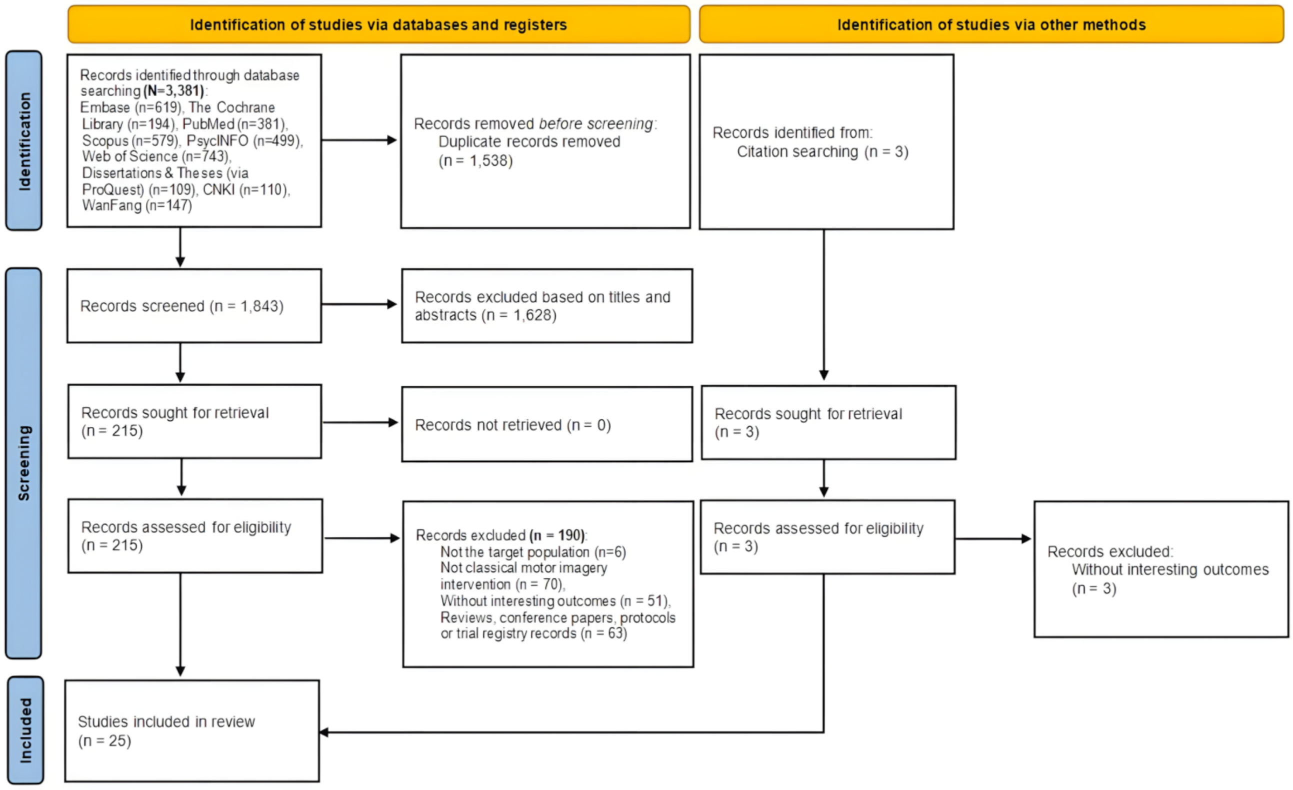

Fig. 1 Flowchart of studies selection

Study characteristics

This scoping review includes 23 RCTs and 1 quasi-experimental trial [36]. Approximately half of the studies were conducted in hospitals/clinics/research institutions (n=12), about one-third of the studies were entirely implemented at home (n=7), and 5 studies shifted study settings from hospitals/clinics to home. As shown in Table 2, these articles, representing a wide range of countries, were published between 2004 and 2024. And there was an apparent increase in publications between 2020 and 2024.

Table 2 Study characteristics and findings

Author (year) [Country]	**Study population** (diagnosis, sample size); **Study setting**	**Exclusion criteria related to the suitability of motor imagery**	**Intervention and control types**	**Cognitive outcomes** (cognitive domains, assessment tools); **Primary or secondary outcome**	**Depression** (assessment tools); **Primary or secondary outcome**	**Key findings**
Kahraman T et al. (2020) [Turkey] [37]	Multiple sclerosis; IG: n=25, CG: n=25; Clinic+home	Severe cognitive impairment	MI; Inactive control: wait list control	1) Attention: SDMT; 2) Memory: the Selective Reminding Test; 3) Visual and spatial working memory: 10/36 Spatial Recall Test; Secondary outcome	HADS; Secondary outcome	Compared to the baseline, the IG exhibited significant improvements in most cognitive functions (except for long term memory), and depression (p < 0.05, d>0.80). No significant changes were observed in the CG in any of the outcome measures.
Paolucci T et al. (2020) [Italy] [38]	Peripheral facial nerve palsy; IG: n=11, CG: n=11; Clinic+home	NR	MI + Mirror therapy + traditional rehabilitation; Active control: traditional rehabilitation	NR	BDI; Secondary outcome	After the intervention, no significant between-group differences in depression. After one-month follow-up, compared to the CG, the IG showed significant improvement in depression (p = 0.017).
Seebacher B et al. (2019) [Austria] [39]	Multiple sclerosis; IG 1: n=20, IG 2: n=20, CG: n=20; Home	Clinical symptoms of depression or cognitive impairment	IG 1: music- and verbally-cued MI; IG 2: music-cued MI; Active control: non-cued MI	NR	Multiple Sclerosis Impact Scale-29 psychological subscore; Secondary outcome	Within-group analyses showed that psychological subdomain improved only in IG 1 (p = 0.030). No significant between-group differences in depression.
Zhang Q et al. (2023) [China] [40]	Stroke; IG: n=60, CG: n=60; Home	Severe cognitive impairment or diagnoses of mental disorders	MI + usual care; Inactive control: usual care	NR	HADS; Primary outcome	After the intervention, the IG showed significantly lower depression scores compared to the CG (d = -2.56, p < 0.001).
Liu L et al. (2020) [China] [41]	Stroke; IG: n=45, CG: n=45; Home	NR	MI + traditional rehabilitation; Active control: traditional rehabilitation	Global cognitive function: MoCA; Primary outcome	NR	After the intervention, the IG showed significantly better cognitive function than the CG (p < 0.001).

Wang Q (2019) [China] [42]	Stroke; IG: n=44, CG: n=44; Hospital	NR	MI + cognitive training; Inactive control: usual care	1) Global cognitive function: Lowenstein Occupational Therapy Cognitive Assessment; 2) Memory: Wechsler Memory Scale; Primary outcome	NR	After the intervention, the IG showed significantly better global cognitive function and memory than the CG ($d = 1.9$, $p < 0.05$).
Chen H (2022) [China] [43]	Aneurysmal subarachnoid hemorrhage, cerebrovascular disease; IG: n=46, CG: n=46; Hospital	Severe cognitive impairment or diagnoses of mental disorders	MI + cognitive training; Active control: traditional rehabilitation	Global cognitive function: MMSE; Primary outcome	NR	After the intervention, the IG showed significantly better cognitive function than the CG ($d = 1.28$, $p < 0.05$).
Wu Y et al. (2016) [China] [44]	The elderly with mobility impairments; IG 1: n=52, IG 2: n=52, CG: n=52; Hospital	NR	IG 1: MI + usual care; IG 2: MI + counterbalance exercise + usual care; Inactive control: usual care	NR	Self-rating depression scale; Secondary outcome	After the intervention, compared to the CG, both IGs showed significant improvement in depression ($d_1 = -0.89$, $d_2 = -1.03$, $p < 0.001$).
Gong W (2017) [China] [45]	Stroke, with mild to moderate cognitive impairment; IG 1: n=33, IG 2: n=33, CG: n=33; Hospital	Severe cognitive impairment or executive dysfunction	IG 1: Targeted cognitive training + conventional cognitive training; IG 2: MI + conventional cognitive training Active control: conventional cognitive training	1) Global cognitive function: MMSE, MoCA; 2) Multi-domain cognitive function: P300 Event-Related Potential; Primary outcome	NR	After the intervention, the cognitive function of both IG 1 and IG 2 was significantly better than that of the CG ($d_1 = 0.96$, $p_1 = 0.019$; $d_2 = 1.41$, $p_2 = 0.021$), but there was no significant difference between the IG 1 and IG 2.
Hu Q (2018) [China] [46]	Elderly patients with cerebral infarction, cerebrovascular disease; IG: n=48, CG: n=47;	NR	MI + conventional cognitive training; Active control: conventional cognitive training	Global cognitive function: MMSE; Primary outcome	NR	After the intervention, the IG showed significantly better cognitive function than the CG ($d = 1.43$, $p < 0.05$).

Zhang N et al. (2022) [China] [47]	Hospital Cerebral infarction with depression, cerebrovascular disease; IG: n=58, CG: n=57; Hospital+home	NR	MI + antidepressant drug; Active control: antidepressant drug	Global cognitive function: MMSE; Secondary outcome	Hamilton Depression Rating Scale; Primary outcome	After the intervention, both cognitive function and depression of the IG were significantly better than those of the CG ($d_{cognitive} = 3.41$, $d_{depression} = -1.79$, $p < 0.05$).
Jiang H et al. (2020) [China] [48]	Stroke, with anxiety and depressive mood; IG: n=50, CG: n=50; Hospital	Severe cognitive impairment	MI + usual care; Inactive control: usual care	NR	HADS; Primary outcome	After the intervention, the depression scores of the IG were significantly improved compared to the CG ($d = -1.80$, $p < 0.001$).
Luo M et al. (2022) [China] [49]	Stroke, with anxiety and depressive mood; IG: n=36, CG: n=36; Hospital	NR	MI + usual care; Inactive control: usual care	NR	HADS; Primary outcome	After the intervention, the depression scores of the IG were significantly improved compared to the CG ($d = -0.72$, $p = 0.003$).
Haire et al. (2021) [Canada] [50]	Stroke; IG 1: n=10, IG 2: n=10, CG: n=10; Research institution	Unilateral spatial neglect, MoCA score ≤ 25	IG 1: 30 minutes of active therapeutic instrumental music performance + 15 minutes of metronome-cued MI; IG 2: 30 minutes of active therapeutic instrumental music performance + 15 minutes of MI without cues; Active control: 45 minutes of active therapeutic	1) Short-term memory: Digit Span Test; 2) Executive function: Trail Making Test-Part B; Secondary outcome	Multiple Affect Adjective Check List-Revised; Secondary outcome	Executive function: Within-group analyses showed that significant improvement occurred only in IG 2. No significant differences among the groups. Memory: None of the three groups showed significant improvement. Mood: Significant improvement was only observed in IG 1.

			instrumental music performance			
Salik et al. (2021) [Turkey] [51]	Spine disease after lumbar spinal surgery; IG: n=19 CG: n=18; Home	NR	MI combined with home rehabilitation; Active control: home rehabilitation	NR	BDI; Secondary outcome	After the intervention, the IG showed a significant decrease in depression (p = 0.023). No significant between-group differences.
Mahmoud et al. (2018) [Egypt] [15]	Parkinson's disease with cognitive impairment; IG: n=15, CG: n=15 Clinic	NR	MI combined with augmented cues of motor learning + cognitive remediation therapy; Active control: cognitive remediation therapy	Using computer-based cognitive assessment device (RehaCom) to assess: 1) attention and concentration; 2) figural memory; Primary outcome	NR	Compared to the CG, the IG had significant improvement in attention and concentration (p = 0.0001) and figural memory (p = 0.0001).
Marusic U et al. (2018) [Slovenia] [12]	Elderly patients after total hip arthroplasty; IG: n=10, CG: n=11; Hospital+home	Mild cognitive impairment	AOMI+standard rehabilitation; Active control: standard rehabilitation	Cognitive inhibition: Dual-Task Walking, the amount of subtracted numbers and errors was monitored. Secondary outcome	NR	No significant between-group differences.
Tamir R et al. (2007) [Israel] [52]	Parkinson's disease ; IG: n=12, CG: n=11 Hospital+home	Dementia	MI + physical practice; Active control: physical practice	1) Executive function and spatial perception: Clock drawing 2) Attention: Stroop Test (parts A and B); Secondary outcome	Unified Parkinson's Disease Rating Scale-mental section; Secondary outcome	Compared to the CG, the IG had significant improvement in mental level (p = 0.09), however no significant between-group differences in cognitive tests.
Dijkerman et al. (2004) [The Netherlands] [36]	Stroke; IG: n=10, CG: n=10 Home	NR	MI + simple reach and grasp task; Inactive control: visual imagery task + simple reach and grasp task	Attention: Elevator counting of the Test of Everyday Attention; Secondary outcome	HADS; Secondary outcome	No significant between-group differences.
Sarasso E et al. (2021) [Italy] [35]	Parkinson's disease IG: n=13 CG: n=12 Clinic	Dementia, medical illnesses, and substance abuse that could	AO + MI + dual-task gait/balance exercises; Active control: dual-task gait/balance	1) Global cognitive function: sub-tests of the computerized Cambridge	NR	After the intervention, the executive function of both IG and CG was significantly improved, but there was no significant difference between the two groups (p = 0.69). Compared to the CG, IG

		impact cognitive function.	exercises + watching landscape videos	Neuropsychological Test Automated Battery. 2) fMRI: task-based fMRI and resting-state fMRI; Secondary outcome		showed significantly reduced recruitment of frontal areas and increased activity of cerebellum during fMRI motor and dual task, correlating with balance/turning velocity and executive improvements. For results of the resting-state fMRI, Group x Time interaction analyses showed that, after training, compared to the CG, the IG showed increased resting-state functional connectivity of the left anterior prefrontal cortex within the anterior salience network and reduced resting-state functional connectivity of the right anterior prefrontal cortex within the anterior default mode network.
Liu W et al. (2022) [China] [53]	Vascular cognitive impairment, cerebrovascular disease; 1) CG: n=10, 2) IG 1: n=11; 3) IG 2: n=11 Hospital	1) Without a certain degree of MI ability (the Movement Imagery Questionnaire-Revised for Stroke, scored ≥25); 2) With abnormal mental state； 3) Severe cognitive impairment.	IG 1: AO + MI; IG 2: AO + MI + conventional cognitive training; Active control: conventional cognitive training	1) Global cognitive function: MoCA; 2) Memory: Rivermead Behavioral Memory Test; 3) Multi-domain cognitive function: P300 Event-Related Potential; Primary outcome	NR	Compared with CG, IG showed significant improvement in post-intervention global cognitive function (d = 1.19, p < 0.001), and memory (d = 0.55, p < 0.001), and also in one-month follow-up assessments (d_{global} = 0.92, p < 0.05; d_{memory} = 0.48, p < 0.05).
Ren Y et al. (2024) [China] [54]	Stroke; IG: n=61, CG: n=61; Hospital	NR	MI + traditional rehabilitation; Active control: traditional rehabilitation	NR	SDS; Primary outcome	After the intervention, the IG showed significantly lower depression scores compared to the CG (d = -0.95, p < 0.001).
Seebacher B et al. (2024) [Austria] [55]	Multiple sclerosis; IG 1: n=44, IG 2: n=44, CG: n=44	Cognitive impairment (MoCA score≤26), moderate	IG 1: Combined cued MI and cued gait training; IG 2: cued MI; Active control: cued	1) Global cognitive function: MoCA; 2) Attention, visual scanning, working memory	HADS; Secondary outcome	Within-group analyses showed a significant improvement in global cognitive function in IG 2 and CG (p < 0.05), while depression showed

	Home	depression/ anxiety (HADS score≥11)	gait training	and psychomotor speed: SDMT; Secondary outcome		improvement only in IG 2 ($p = 0.033$). After the intervention, no significant between-group differences in cognitive function and depression.
Karakas H et al. (2024) [Turkey] [13]	Multiple sclerosis; IG: n=16, CG: n=16; Home	Severe cognitive impairment or psychiatric illness	Iateralization training (implicit MI) + MI + usual care; Inactive control: usual care	1) Attention: SDMT; 2) Learning and memory: California Verbal Learning Test-Second Edition + Brief Visuospatial Memory Test-Revised; Secondary outcome	HADS; Secondary outcome	IG showed significant reduction in post-intervention depression (d= -1.09, p = 0.009), along with improvements in attention and learning and memory when compared to the CG at both post-intervention (attention $d = 0.87$, $p = 0.026$; memory $d = 1.28$, $p = 0.002$) and one-month follow-up assessments (attention $d = 0.81$, $p = 0.046$; memory $d = 0.91$, $p = 0.023$).

AO:action observation; AOMI: action observation and motor imagery; BDI: Beck Depression Inventory; CG: control group; *d*, Cohen's *d*; HADS: Hospital Anxiety and Depression Scale; IG: intervention group; MMSE: Mini-Mental State Examination; MOCA: Montreal Cognitive Assessment; MI: motor imagery; NR: not reported; SDMT: Symbol Digit Modalities Test; SDS: Self-rating depression scale; fMRI: functional magnetic resonance imaging.

Participants' characteristics

The sample size in the included studies ranged from 20 to 156, with a median of 66 (Table 2). The health conditions of participants mainly comprised neurological disorders, including cerebrovascular disease (n=13), multiple sclerosis (n=4), Parkinson's disease (n=3), and peripheral facial nerve palsy (n=1). Additionally, three studies targeted orthopedic postoperative conditions (n=2) and elderly mobility impairments (n=1). All participants in the three studies had cognitive impairment [15, 45, 53], whereas participants in three other studies were diagnosed with depressive mood [47-49]. Thirteen studies placed restrictions on the severity of cognitive impairment during recruitment, and nine of them excluded individuals with severe cognitive impairment or dementia [13, 35, 37, 40, 43, 45, 48, 52, 53]. Four studies excluded individuals with abnormal mental states [13, 53], depressive symptoms [39], or diagnoses of mental disorders [40, 43, 55]. Moreover, one study required eligible participants to possess a certain level of motor imagery ability [53]; one excluded individuals with executive dysfunction [45], while another excluded those with unilateral spatial neglect [50].

Intervention characteristics

As shown in Table 2, 7 studies primarily and solely conducted motor imagery interventions. And 17 studies used combined approaches on the basis of motor imagery, including traditional rehabilitation (n=8) [12, 35, 38, 41, 44, 51, 52, 54], cognitive training (n=6) [15, 42, 43, 45, 46, 53], action observation (n=3) [12, 35, 53], antidepressants (n=1) [47], lateralization training (i.e., left/right judgment tasks for body sides, n=1) [13], and therapeutic instrumental music performance (n=1) [50]. Eight studies employed an inactive control group (i.e., usual care or wait list control) [36, 37, 40, 42, 44, 48, 49, 55]. The others set active control groups, mainly including traditional rehabilitation (n=8) [12, 35, 38, 41, 43, 51, 52, 54] and cognitive training (n=4) [15, 45, 46, 53].

The characteristics of motor imagery intervention delivery

As summarized in Table 3, modes of intervention delivery mainly included recorded audios/videos (n=11, 45.8%) [12, 35, 39, 41, 47-49, 51, 53-55] and face-to-face intervention (n=9, 37.5%) [15, 38, 42-46, 50, 52]. And all the participants received the motor imagery interventions individually, regardless of the modes of delivery. Six studies (25%) conducted self-training motor imagery at home with weekly phone call support [36, 39, 41, 51, 54, 55]. The duration of interventions varied among studies and was related to the frequency: daily administration was common for interventions lasting one month or less, and 2-3 times per week for those lasting around 2 months. Most studies set the length of a single motor imagery session at 20 to 30 minutes (n=9, 37.5%) [12, 37, 40, 42, 46-48, 53, 55]. Five studies (20.8%) used training diaries [15, 36, 39, 51, 55] and/or interviews [36] to record mental activities during the intervention process to monitor or assess the completion of motor imagery.

Table 3 Summative results of intervention delivery

Category	Number of studies	Percentage	Studies
Intervention provider			
Therapist	15	62.5%	[12, 15, 35, 37, 38, 43-50, 52, 53]
Self-training	6	25.0%	[36, 39, 41, 51, 54, 55]
Therapist+self-training	1	4.2%	[13]
Nurse	2	8.3%	[40, 42]
Delivery mode			
Face-to-face intervention	9	37.5%	[15, 38, 42-46, 50, 52]
Recorded audios	6	25.0%	[39, 47-49, 51, 55]
Recorded videos	5	20.8%	[12, 35, 41, 53, 54]
Phone/video call	3	12.5%	[13, 37, 40]
Written script	1	4.2%	[36]
Delivery dosages			
Duration			
＜ 1 month	3	12.5%	[44, 48, 50]
1 month	6	25.0%	[36, 39, 46, 47, 49, 55]
1.5 months	3	12.5%	[15, 35, 51]
2 months	8	33.3%	[12, 13, 37, 41, 42, 45, 53, 54]
3 months	4	16.7%	[38, 40, 43, 52]
Frequency			
2 times per week	5	20.8%	[13, 37, 38, 40, 52]
3 times per week	3	12.5%	[12, 35, 50]

4~6 times per week	6	25.0%	[15, 39, 43, 53-55]
Daily	10	41.7%	[36, 41, 42, 44-49, 51]
Length of each session			
15~＜20 mins	5	20.8%	[39, 41, 44, 45, 49]
20~30 mins	9	37.5%	[12, 37, 40, 42, 46-48, 53, 55]
＞30 mins	8	33.3%	[13, 15, 35, 38, 43, 50, 52, 54]
Not report	2	8.3%	[36, 51]
Monitoring and evaluation of each motor imagery process			
None	19	79.2%	[12, 13, 35, 37, 38, 40-50, 52-54]
Diaries of motor imagery experiences or post-intervention interviews	5	20.8%	[15, 36, 39, 51, 55]

The contents of motor imagery strategies

Figure 2 depicts the specific elements of the motor imagery strategies reported by the included studies based on the PETTLEP model. Table S1 (Supplementary Materials) contains detailed descriptions of each study's motor imagery procedure. Only two studies contained all the elements mentioned in the PETTLEP model [39, 55]. Over half of the studies did not report contents related to 'Environment,' 'Timing,' and 'Emotion,' with 'Emotion' being the least reported element (n=21, 87.5%). Approximately half of the studies (n=13, 54.2%) gave individuals brief relaxation exercises before motor imagery (Physical). Six studies (25%) reported using multisensory environmental cues, including auditory, visual, tactile, and olfactory cues, to imitate real-world performance situations while participants were imaging (Environment). Studies concentrating on cognitive function used functional exercises and/or activities of daily living as task materials, whereas those focusing on depression frequently used walking exercises (Task). In terms of Timing, seven studies (29.2%) used auditory cues (i.e., instrumental music, metronome tempo, and motor instructions) or visual cues (i.e., demonstration of the imagined motor) to indicate temporal rhythm, allowing participants to adjust the pace of their imagery processing. Only three studies (12.5%) included motivating and positive feedback in instructions to promote emotional shifts during MI (Emotion). Fifteen studies (62.5%) required participants to perform motor imagery from a first-person perspective.

Reference	**P** (Physical)				**E** (Environment)			**T** (Tasks)						**T** (Timing)			**L** (Learning)			**E** (Emotion)			**P** (Perspective)			
	Brief relaxation exercises before motor imagery	Position of performers: Sitting position	Position of performers: Supine position	Not report	Create a virtual environment via multisensory environmental cues	Let performers imagine themselves in a familiar and relaxing virtual environment	Not report	Functional exercises targeted at functional deficits	Walking	Activities of daily living	Functional exercises + walking	Functional exercises + activities of daily living	Tai Chi + activities of daily living	Use auditory cues to indicate temporal rhythm	Use visual and auditory cues to indicate temporal rhythm	Not report	Progress with training effectiveness and familiarization	Repeated practice	Not report	Positive feedback	Motivational and arousal enhancing aspects included in instructions	Not report	First-person perspective	Third-person perspective	Interactional perspectives	Not report
Kahraman T 2020	X	X			X			X								X	X			X					X	
Paolucci T 2020				X			X	X								X			X			X	X			
Seebacher B 2019		X				X			X					X			X				X		X			
Zhang Q 2023	X		X		X							X				X		X				X				X
Liu L 2020			X				X				X					X	X					X	X			
Wang Q 2019	X		X				X		X							X			X			X			X	
Chen H 2022				X			X	X								X		X				X	X			
Wu Y 2016	X		X				X			X						X			X			X	X			
Gong W 2017				X			X						X			X			X			X	X			
Hu Q 2018	X						X					X				X			X			X	X			
Zhang N 2022	X				X				X							X			X			X				X
Jiang H 2020	X		X		X				X							X			X			X	X			
Luo M 2022	X		X		X				X							X			X			X	X			
Haire 2021				X			X					X		X					X			X				X
Salik 2021	X					X		X						X			X					X	X			
Mahmoud 2018	X	X					X				X				X		X	X				X	X			
Marusic U 2018	X						X		X					X			X					X	X			
Tamir R 2007				X	X				X					X			X					X			X	
Dijkerman 2004				X			X	X								X			X			X	X			
Sarasso E 2021				X			X	X								X	X					X	X			
Liu W 2022				X			X			X						X			X			X			X	
Ren Y 2024	X		X				X					X				X			X			X				X
Seebacher B 2024		X				X			X					X			X				X		X			
Karakas H 2024	X						X	X								X	X					X				X

Fig. 2 Overview of extracted motor imagery strategy elements based on PETTLEP model

The feasibility and acceptability of motor imagery interventions

There were 8 studies reporting recruitment rates [12, 13, 15, 35, 36, 39, 51, 53], ranging from 41.3% [12] to 92.7% [51] (median value 73.5%). Participants' dropout rates in intervention groups ranged from 0% [40-48, 50, 51, 54] to 24.0% [15, 37] (median value 2.8%). None of the studies reported any adverse events related to motor imagery interventions. The reported average adherence rate exceeded 90%. One study reported participants' satisfaction of the intervention in the form of qualitative feedback. It was stated that home-based motor imagery was safe and convenient [39].

Older participants in one study reported difficulty watching the guided materials and conducting motor imagery at the same time [12].

Quality assessment

The review encompassed 1 quasi-experimental study and 23 RCTs. The quality scores for the RCTs varied from 6 to 13, while the quasi-experimental study received a score of 8. Notably, 13 RCTs reported participant dropouts during the intervention delivery, without analyses of the impact of loss to follow-up on results. Additionally, studies reporting drop-out cases commonly used the per-protocol analysis strategy. Due to the nature of the motor imagery intervention, participants and those delivering the treatment were aware of participant allocation. The quasi-experimental study lacked detailed information regarding participant retention. The quality assessment for each included study is outlined in Supplementary Tables S2 and S3.

The effectiveness and potential mechanisms underlying motor imagery interventions on cognitive function and depression

Outcomes and measurements

Sixteen studies reported data on cognitive function [12, 13, 15, 35-37, 41-43, 45-47, 50, 52, 53, 55], of which seven considered it the primary outcome [15, 41-43, 45, 46, 53]. In addition to global cognitive function (n=9) [35, 41-43, 45-47, 53, 55], the included studies mainly reported findings on memory (n=7) [13, 15, 37, 42, 50, 52, 53], attention (n=6) [13, 15, 36, 37, 52, 55], and executive function (n=4) [12, 37, 50, 52]. Fifteen studies reported data on depression [13, 36-40, 44, 47-52, 54, 55], with five identifying it as the primary outcome [40, 47-49, 54]. Three studies reported short-term follow-up effects on cognitive function (n=2) [13, 53] and depression (n=2) [13, 38], with all follow-up periods set as one month. No study conducted a long-term follow-up. Table 2 shows the assessment tools used in the studies, which were mostly cognitive and psychological questionnaires. Two studies used electroencephalography to measure the P300 Event-Related Potential, which is a characteristic brain electric activity associated with cognitive function [45, 53]. Another study reported functional magnetic resonance imaging indicators linked to cognitive function, specifically including alterations in the brain's functional connectivity during the resting state and brain activities during the motor imagery process [35]. In the following sections, we synthesize the findings from each individual study on intervention effects and potential mechanisms for the following health conditions: neurological disorders, after orthopedic surgery, and elderly mobility impairments.

Effects on cognitive function and depression

In terms of the 16 studies assessing cognitive function, 15 focused on neurological disorders. Among them, 66.7% (n=10) reported a significant positive difference in post-intervention cognitive function compared to the control group, encompassing global cognitive function [41-43, 45-47, 53], memory [13, 15, 42, 53], attention [13, 15], and executive function [35], with effect sizes ranging from 0.48 [53] to 3.41 [47]. Only two studies, focusing on adults with vascular cognitive impairment and multiple sclerosis, reported one-month follow-up outcomes for global cognitive function, attention, and memory, with both indicating residual effects ($p<0.05$) [13, 53]. The study, which focused on elderly patients following total hip arthroplasty without follow-up, found no significant differences between the groups [12].

In terms of the 15 studies assessing depression, 13 focused on neurological disorders, while 2 addressed elderly mobility impairments and orthopedic postoperative conditions. Among the 13 ones, 53.8% (n=7) [13, 40, 47-49, 52, 54] reported a significant positive difference in post-intervention depression compared to the control group, with effect sizes ranging from -0.72 [49] to -2.56 [40]. One study found no significant intergroup differences post-intervention; however, it did observe a significant alleviation in depression in the motor imagery group compared to the control group at the one-month follow-up [38]. However, Karakas H et al. found that motor imagery's effect on depression was not sustained at the one-month follow-up [13]. Only one of the two studies on mobility impairments showed significant reductions in depression following the motor imagery intervention (d = -0.89, $p < 0.001$) [44].

Potential mechanisms

There were five studies, focused on neurological disorders, explored the potential mechanisms underlying motor imagery interventions for cognitive function and depression, which were classified into three categories: neurobiological mechanisms (n=3) [35, 41, 45], biochemical mechanisms (n=1) [47], and psychological mechanisms (n=1) [13]. Three studies employed neuroimaging techniques to explore the beneficial effects of motor imagery interventions on brain neuroplasticity and functional connectivity [35, 41, 45]. Two of them both reported the P300 Event-Related Potential latency decreased and the amplitude increased among adults with stroke or vascular cognitive impairment, which confirmed the benefits of motor imagery interventions in the neural substrates of attention and executive function [45, 53]. A study using task-based functional magnetic resonance imaging revealed that during the motor imagery process, there was a specific functional reorganization in the brain regions of individuals with Parkinson's disease [35]. Specifically, there was a decrease in frontal region recruitment and an increase in cerebellar activity, indicating improved executive and motor functioning [35]. The secondary analysis of this study indicated an enhancement in resting-state functional connectivity in the anterior prefrontal cortex after motor imagery training. Such a frontal functional reorganization was associated with better accuracy in set-shifting and led to an improved executive function [34].

In terms of biochemical mechanisms, one study preliminarily confirmed that motor imagery could give rise to beneficial neurological changes by facilitating the secretion of brain-derived neurotrophic factor, which may explain the positive effects on both cognitive function and depression among adults with cerebral infarction [47]. For psychological mechanisms, one study preliminary explored the potential benefits of reduced pain perception following motor imagery in improving cognitive function and depression in adults with multiple sclerosis [13]. A study focusing on post-lumbar surgery patients also indicated that alterations in pain perception may play a role as a mediator in the alleviation of depression following motor imagery interventions. Other studies focusing on mobility impairments did not explore the potential working mechanisms [51].

Discussion

This is the first known scoping review to present a comprehensive synthesis of evidence on motor imagery interventions designed to improve cognitive function and depression. It provides a holistic review of target populations, imagery strategies, delivery characteristics, acceptability, effectiveness, and possible mechanisms. Seventeen of the twenty-four included studies were published in the last five years, indicating that motor imagery is an emerging and promising intervention for cognitive impairment and depression.

We preliminarily identified the characteristics of the target population regarding cognitive function and emotional state. An obstacle to the application of motor imagery in this context is the controversy regarding the setting of eligibility criteria related to cognitive function and emotional state, as both of these conditions may potentially affect participants' ability to generate and sustain vivid motor images [56, 57]. Based on the characteristics of the included participants, adults with mild to moderate cognitive impairment can still benefit from the training. However, severe cognitive impairments are generally deemed inappropriate for this intervention [13, 35, 37, 40, 43, 45, 48, 52, 53]. The studies reviewed do not reach a consensus on the impact of depression or depressive symptoms on the execution of motor imagery. Providing a video or live display of actions, which was employed in several studies, has been shown to help participants generate and maintain vivid imagery at an appropriate pace [58]. Moreover, the provision of video stimuli could relax the requirements of cognitive function to participant in motor imagery training [59].

Overall, the delivery characteristics of the interventions were heterogeneous in terms of mode, session length, and frequency. A considerable portion of motor imagery interventions was conducted as self-training at home. When properly instructed, motor imagery techniques can be self-administered and may be more cost-effective than ongoing interventions such as cognitive training and psychological therapies, potentially leading to reduced healthcare costs [13]. Evidence indicates that a single session lasting over 20 minutes could lead to mental fatigue due to heightened attention demands, potentially diminishing the efficacy of motor imagery [60, 61]. A systematic review reported that around 17 minutes of motor imagery is optimal to observe beneficial effects on physical performance [31]. The duration of each session in the included studies is typically set at 20~30 minutes, without documented adverse events. However, further research is still needed to determine whether this duration is optimal for the effectiveness of motor imagery in addressing cognitive impairment and depression. During the motor imagery process, participants typically do not exhibit overt actions, which makes it challenging to objectively assess their mental effort and motor imagery performance. Only a few studies assessed the process quality through qualitative methods [15, 36, 39, 51]. Objective measurements like electrooculography, electroencephalography, and electrodermal response analysis could also be considered in future research [62-64].

Most studies reported significant improvements in cognitive function and depression following the interventions. However, only a minority of them, with small sample sizes, explored the mechanisms behind motor imagery, lacking consistency and preventing definitive conclusions on these pathways. Neuroimaging evidence from the included study indicated that motor imagery activated brain regions associated with cognitive and motor functions, particularly in the anterior prefrontal cortex, thereby facilitating functional reorganization in these areas [35, 45, 53]. This beneficial effect on brain neuroplasticity offers insights into the enhanced cognitive function. However, this study limited its analysis to hypothesis-driven regions of interest due to small sample sizes; future research should broaden the analysis to encompass the entire brain [35]. Findings from electroencephalography testings showed that alterations in event-related potentials during motor imagery were similar to those observed during aerobic exercise, suggesting a strong functional equivalence between motor execution and imagery in bolstering cognitive function [65]. Brain-derived neurotrophic factor could augment neurogenesis and improve synaptic plasticity [66]. Reduced levels of this factor have been identified as risk factors in developing depressive disorder and cognitive impairment [67]. Preliminary evidence indicates that motor imagery can enhance its expression, fostering neuroplasticity and the development of alternative motor circuits, which benefits both cognitive function and depression [47]. Additionally, significant pain reduction was documented in adults with multiple sclerosis and post-lumbar surgery patients following motor imagery [51]. Motor imagery can activate motor cortical networks and induce an increase in cortical excitability, which is associated with a decrease in pain perception [68]. Despite the absence of direct evidence for causal inferences regarding the mediation relationship, the established connection between pain, cognitive impairment, and depression suggests that motor imagery could be a promising therapeutic approach.

There are some possible explanations for these non-significant findings. First, half of the included studies primarily targeted physical functions or pain rather than cognitive function or depression. And some participants had preserved cognitive function at baseline, which limited the benefits they could obtain from motor imagery. Furthermore, some studies remained at the pilot stage with small sample sizes, which are thought to be insufficient to detect significant differences compared to controls. In addition, given the lack of baseline assessment for motor imagery ability and the evaluation of motor imagery performance quality, the results may be influenced by group composition and heterogeneity.

When applying the results of this scoping review in practice, it should be noted that this study concentrated on the application of classical motor imagery. Secondly, significant heterogeneity exists among the included studies in aspects such as disease diagnosis, delivery methods, and outcome assessments. Some of the included studies are feasibility or pilot studies, which implies they may have limitations including inadequate sample sizes, short observation periods for outcomes, and flaws in experimental design. This could potentially undermine the reliability of the conclusions. Furthermore, it is possible that studies published in other languages may have been overlooked. Additionally, caution is advised when evaluating effectiveness due to the limited quality of the included studies.

Based on a comprehensive review of the existing literature, motor imagery demonstrates high feasibility and acceptability as a preventive and interventional therapy to significantly improve cognitive function and depression with moderate-to-large effect sizes in adults with neurological disorders and/or mobility impairments. However, there is a lack of available evidence regarding the specific mechanisms underlying these effects. This review preliminary established that motor imagery can relieve pain perception, activate brain regions associated with motor and cognitive functions, and facilitate the secretion of neurotrophic factors. Robustly designed RCTs are needed to evaluate the long-term follow-up effects on specific cognitive function domains and depression. It is recommended to use more neuroimaging techniques to understand the impact of motor imagery on the neuroplasticity and brain's functional reorganization, which will contribute to the development of mechanism-driven interventions.

Statements and declarations

Ethical considerations

There was no need for ethical approval or informed consent since this was a second study based on the literature.

Conflict of interest statement

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Data availability statement

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