Motor Imagery Training After Stroke: A Systematic Review and Meta-analysis of Randomized Controlled Trials

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Background and Purpose: A number of studies have suggested that imagery training (motor imagery [MI]) has value for improving motor function in persons with neurologic conditions. We performed a systematic review and meta-analysis to assess the available literature related to efficacy of MI in the recovery of individuals after stroke.

Methods: We searched the following databases: PubMed, Web of Knowledge, Scopus, Cochrane, and PEDro. Two reviewers independently selected clinical trials that investigated the effect of MI on outcomes commonly investigated in studies of stroke recovery. Quality and risk of bias of each study were assessed.

Results: Of the 1156 articles found, 32 articles were included. There was a high heterogeneity of protocols among studies. Most studies showed benefits of MI, albeit with a large proportion of low-quality studies. The meta-analysis of all studies, regardless of quality, revealed significant differences on overall analysis for outcomes related to balance, lower limb/gait, and upper limb. However, when only high-quality studies were included, no significant difference was found. On subgroup analyses, MI was associated with balance gains on the Functional Reach Test and improved performance on the Timed Up and
行走计时 Go, gait speed, Action Research Arm Test, and the Fugl-Meyer Upper Limb subscale.

Discussion and Conclusions: Our review reported a high heterogeneity in methodological quality of the studies and conflicting results. More high-quality studies and greater standardization of interventions are needed to determine the value of MI for persons with stroke.

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Video Abstract available for more insights from the authors (see Video, Supplemental Digital Content 1, http://links.lww.com/JNPT/A188).

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INTRODUCTION

There are innumerable physical therapeutic approaches used to improve motor control in persons recovering from stroke. These therapies aim to improve the biomechanical performance of lost or limited movements,[1] enhance the neuroplasticity mechanisms that occur after central nervous system lesions,[2] avoid disuse, and promote function. Within this context, the discovery of mirror neurons in the 1990s led to the development of new therapeutic techniques and approaches based on cognitive strategies, such as the use of virtual reality, mirror therapy, action observation, and motor imagery (MI).[3,4]

Motor imagery entails the cognitive task of imagining the performance of a given movement or specific task without physically executing it.[5,6] During MI, also known as "mental practice," the mental imagery of the movement or task to be learned is systematically repeated.[5] Studies using noninvasive brain stimulation techniques have allowed observation of cortical activation in motor areas during MI,[7] and neuroimaging studies have shown that there is cortical reorganization after MI in persons with stroke.[8]

Over the past decade, there has been growing interest in observing the effects of the MI on the recovery of neurologic deficits such as those observed after stroke. Many clinical trials,[8-15] systematic reviews,[16-19] and meta-analyses[6,20] have also highlighted the viability and benefits of MI for functional recovery when combined with conventional physical exercise protocols.[19] However, a wide variety of intervention protocols exist in the literature, differing on aspects such as duration, frequency of MI exposure, and movements or tasks trained.[19] In addition, few clinical trials using MI have strong methodological design despite recognition of the importance of methodological rigor and need for consensus related to the use of therapies in rehabilitation after stroke.[1]

Although previous systematic reviews and meta-analyses have assessed clinical trials of MI interventions, no meta-analysis globally assessing the topic with different outcomes such as gait, balance, activities of daily living, and recovery in the upper limb is available. Likewise, to our knowledge, this is the first attempt to describe the methodology used in clinical trials subdivided according to outcome measure investigated in poststroke recovery, facilitating understanding of the clinical impact and scientific relevance of MI. Considering the promising clinical relevance of MI, our research question was as follows: "In individuals after stroke, does MI training have efficacy for improving balance, activities of daily living, and upper limb and lower limb functions when compared with a control intervention?"

METHODS

Identification and Selection of Studies

The present study constituted a systematic review and meta-analysis of randomized clinical trials investigating the efficacy of MI for recovery after stroke. Since efficacy can only be demonstrated when there is comparison with another intervention, all studies included were randomized trials. A qualitative analysis of randomized clinical trials selected using a systematic review based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) was carried out. The study was registered on PROSPERO under registration CRD42016041326.

In January 2016, a search, with no restriction on the language or publication date of articles, was conducted using several databases relevant in the context of the present scientific clinical investigation, namely, PubMed, ISI Web of Knowledge, Scopus, Cochrane, and Physiotherapy Evidence Database (PEDro). The key words related to the subject were selected on the basis of a review of the literature. The key words were then grouped into a single Boolean expression as follows:

(imagery OR "mental imagery" OR "kinesthetic imagery" OR "motor imagery" OR "visual imagery" OR "mental practice" OR "mental training" OR "mental rehearsal") AND (stroke OR "cerebrovascular accident" OR "stroke rehabilitation" OR "stroke recovery" OR "hemiparesis" OR paresis OR ischemia) AND (randomized OR randomised OR trial OR "controlled trial").

The search tool available for the PEDro database precluded the use of the Boolean expression.[21] The methodological strategy employed in this case was to perform searches associated with the terms "clinical trial" with "imagery," "mental practice," "mental training," and "mental rehearsal."

Assessment of Characteristics of Studies

Phase 1

In Phase 1, searches for studies in the selected databases using the Boolean expression were carried out by 2 different researchers. Duplicate studies were then excluded, and the preliminary analysis based on titles and abstracts was performed. Subsequently, all studies representing entries in annals of congresses or book chapters, those not relevant to topic, observational studies, reviews, studies not investigating MI poststroke, and studies investigating other cognitive intervention strategies such as observation of movement or cognitive training were excluded. A manual search based on the references of other articles was also carried out.

Phase 2

Phase 2 entailed searching for the full texts of articles available for download. We excluded protocols of clinical trials, interventions with robotics or computer-brain interface, clinical trials with no control group or statistical analysis, and nonrandomized clinical trials.

Phase 3

Given the diversity of the studies retrieved, in Phase 3, the studies were subdivided according to the outcome measures assessed: Balance group—balance-related measures, ADL group—measures related to performance of activities of daily living (ADL), Lower Limb and Gait (LL/Gait) group—measures of motor performance of affected lower limb and gait performance, and Upper Limb (UL) group—measures of motor performance of affected upper limb. Some studies appeared in more than 1 subgroup because they reported data on more than 1 outcome. After subdivision, only studies containing mean and standard deviation data for the outcomes investigated were included. The PRISMA flowchart adopted is depicted in Figure 1. The data extracted from each study were as follows: (1) sample size; (2) time since stroke; (3) intervention protocol (type, frequency, duration, and follow-up); (4) scales or measuring instruments; and (5) result of interventions.

Quality

Given the type of intervention being investigated, the studies are not considered double-blind, as even when the assessor is blinded (ie, single-blind), participants are aware of the group to which they are allocated. Therefore, the risk of bias of each study was assessed using the Cochrane Back Review Group Criteria List for Methodological Quality Assessment,[22] comprising 11 items investigating methodological aspects considered relevant in the quality of clinical trials. We selected this quality assessment tool, as we deemed it to be most applicable for studies having the methodological limitation of an absence of double-blinding. The quality analysis was initially performed by one assessor and then independently by another assessor. Any disparities in the conclusions of the quality analysis were then jointly examined by the 2 assessors, who came to consensus regarding the most appropriate score according to the criteria from the scale. On the basis of previous studies, a minimum cutoff score of 6 points was established, wherein studies with a score 6 or more points were considered to have the most adequate methodology.[23] A list of methodological quality based on the score obtained on the PEDro scale is provided (see Supplemental Digital Content 2, http://links.lww.com/JNPT/A189).

Participants

The clinical trials included in our systematic review investigated the effect of MI on motor and sensory recovery of individuals clinically diagnosed with stroke; no restrictions on the type or time since neurovascular event were imposed.

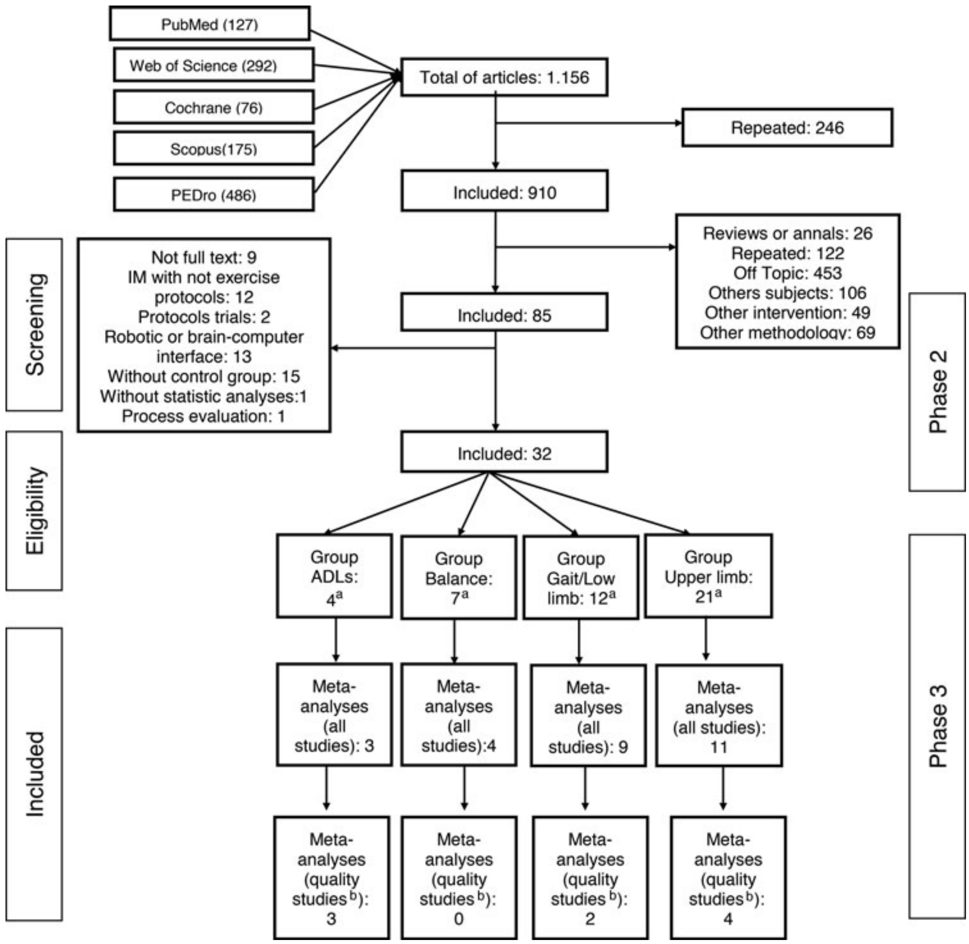

Figure 1. PRISMA flowchart. [a]Studies measuring more than 1 outcome. [b]Studies with a quality of 6 or more on the Cochrane scale. ADL, activities of daily living; IM, motor imagery.

Intervention

The intervention protocol with MI had to entail individuals performing mental imagery of specific movements or tasks, without restriction on MI strategy (such as visual or kinesthetic imagery), or number of repetitions. Also, no restrictions were placed on the presence or absence of strategies promoting imagery, such as films, audio tapes, or images related to the movements or tasks to be imagined, among others.

Outcomes

The primary outcomes investigated in this review were the effects of MI both on performance of ADL and on motor function of balance, gait, and upper limbs.

Data Analysis

The meta-analysis was performed using the RevMan 5.2 program of the Cochrane with comparison between the experimental (or intervention) group and the control group (other intervention or waiting list). In studies involving more than 1 control group, the analysis was done separately on the data from the experimental group with the respective control group.

The effect size for outcomes was retrieved from mean, standard deviation, and group size. Given the wide range of outcomes found, the meta-analysis was performed using 3 different analyses as follows. First, in Analysis 1, a meta-analysis including all the studies irrespective of quality and scale used, divided into major outcomes Balance, ADL, LL/Gait, and UL, was performed. Second, in Analysis 2, the studies were further subdivided according to the scale used (ie, Timed Up and Go [TUG], Action Research Arm Test [ARAT], Fugl-Meyer Lower Limb [FMLL] subscale. Finally, Analysis 3 included only studies with adequate methodological quality ($\geq$6 points on the Cochrane scale) for each of the 4 outcome groups analyzed.[24] Random-effects models were employed considering the possible heterogeneity in the scales used by the studies.

For the meta-analyses that compiled different scales, the size effect was calculated by the standardized mean difference (SMD) with its 95% confidence interval (CI). This approach enabled us to include different outcome measures in the same synthesis. For the meta-analyses assessing studies that used the same scales (ie, meta-analysis assessing studies that used the ARAT), the effect size was calculated by the raw mean difference, which is appropriate when all studies in the analysis used the same scale.[25]

Some scales measuring gait or upper limb function indicate improvement by increases in values (eg, gait speed), whereas other scales indicate improvement by decreases in values (eg, TUG). To adjust for the different scale directions, for those scales that report improvement with decreasing values, we transformed the values by multiplying the values by −1.[26] Finally, funnel plots were produced to provide a more in-depth analysis of the heterogeneity of studies and publication bias (see Supplemental Digital Content 2, http://links.lww.com/JNPT/A189). In the funnel plots, there is an notable asymmetry. Although there are several causes of asymmetrical funnel plots, these findings may reveal the presence of bias or heterogeneity.

RESULTS

Flow of Studies Through Review

Of the 1156 articles found in the database, a total of 32 articles were included in the systematic review and analyzed for methodological quality.[8-15,27-50] Details related to selection of articles are included in the PRISM flowchart (Figure 1).

Description of Studies

The general characteristics of the studies included are shown in Table 1. Of the 32 studies included, the majority (22 studies; 68.8%) were published between 2011 and 2015.

Quality: Risk of Bias in Individual Studies

The methodological quality, together with final scores, of each article is given in Table 2. Although none of the studies attained a maximum score of 11, owing to the fact that none employed double-blinding, 13 (40.6%) articles had a score of 6 or more, indicating adequate methodological quality.* The highest score (9 points) on the Cochrane scale was achieved by the study of Verma et al.[15]

Participants

The total sample comprised 955 persons with post–ischemic or hemorrhagic stroke seen in the acute/subacute (59.3% with <6 months) phase of stroke. Two studies did not report the time elapsed since neurovascular injury.[31,32] The population studied showed motor (29 studies)[8-15,28-45,47-49] and sensory/perceptive (3 studies)[27,46,50] impairments after neurovascular injury.

Intervention

In most of the studies, participants performed MI in association with conventional or traditional physical and/or occupational therapy. Only the study by Dickstein et al[12] used MI alone as an intervention for the experimental group and did not describe combining MI with any other intervention.

Large differences in exposure times of MI protocols were noted. A total of 11 (34.4%) studies used 30 minutes of MI,† whereas the minimum time was 5 minutes (in only 1 study).[34] There were also differences in the number of intervention sessions in each study. The most common number of sessions reported was 12, adopted in 9 (28.1%) studies.‡ In 12 (37.5%) studies, persons with stroke received the intervention for 4 weeks,§ whereas in 9 (28.1%) studies, the intervention period was 6 weeks.¶ With regard to the type of MI applied, 13 (40.6%) studies‖ used internal imagery perspective of movements or specific tasks, 11 (34.4%) studies used both internal and external perspectives,# 1 study used the external imagery perspective alone,[43] and 7 studies did not specify perspective.[9,13,15,36,37,41,47]

Outcomes

Regarding the outcome measures investigated, 5 studies involving a total sample of 272 persons with stroke sought to assess the effects of the intervention on performance of ADL.[10,13,30,36,37] Seven studies aimed at investigating the Balance group before and after the intervention, involving a total sample of 206 persons with disabilities after stroke.[9-12,29,34,48] Twelve studies investigated motor performance of lower limb and/or gait in an overall sample of 343 persons.** After dividing all studies into subgroups, 9 studies were found to assess two or more outcomes (e.g. gait and balance).[9-12,29,30,34,36,37]

Effect of Intervention

Concerning the domains of effects investigated by the studies, the domains of activity and of body structure and function were covered, reflecting a large variability in the measures adopted by the studies. Five (15.6%) studies assessed the effects of the intervention on performance of activities of daily living,[10,13,30,36,37] 12 (37.5%) studies†† assessed the effects on motor recovery of lower limb and/or gait, and, finally, and 20 (62.5%) studies assessed performance and motor recovery of upper limb.‡‡

With regard to the outcomes of the included studies, positive results (ie, the MI group with better outcomes than the control group) were found in 50% of the studies from the subgroup for activities of daily living, 85.7% of the Balance subgroup, 92.3% from the LL/Gait subgroup, and 80.9% of the studies from the UL group. Three studies reported both positive and neutral outcomes, whereas none of the studies had results where measures were worse following the MI intervention.

Conflicts of Interest of the Studies Included

Of the 32 studies included, only 9 (28.1%) studies§§ declared no conflicts of interest, whereas 23 studies did not

*References 10, 15, 27, 30, 36, 37, 40, 41, 44, 47-50.

†References 8, 14, 28, 29, 31, 33, 37, 39, 42, 45, 50.

‡References 9, 12, 14, 30, 31, 38, 40, 43, 45.

§References 8, 9, 12, 29-32, 35, 38, 39, 43, 46.

¶References 10, 11, 14, 15, 33, 40, 42, 45, 49, 50.

‖References 8, 14, 28, 30, 32, 35, 38, 39, 45, 46, 48-50.

#References 10-12, 27, 29, 31, 33, 34, 40, 42, 44.

**References 9-12, 15, 29, 32-34, 37, 38, 42.

††References 9-12, 15, 29, 32-34, 37, 38, 42.

‡‡References 8, 10, 14, 27, 28, 30, 31, 35-37, 39-41, 43-47, 49, 50.

§§References 8, 10, 12, 14, 28, 35, 36, 48, 49.

Table 1. Characteristics of Studies

Author (Year)	Time Since Stroke, mo	Sample Size	Outcome	Outcome Test	Type of Intervention	Number of Sessions/ Duration of Session, min	Follow-up, wk	Result Compared With Control Groups
Bae et al (2015)	<3	20	Balance, Gait	BBS, TUG, FRT, FSST	Balance exercises + MI	12/10	4	+
Braun et al (2012)	<3	36	Balance, ADL, Gait/LL, and UL	MOI, BI, NHPT, BBS, RMI, 10mWT	Physiotherapy + MI	?/10 or 20	6	N
Cho et al (2012)	>12	28	Balance, Gait	FRT, TUG, 10mWT, FMLL	Gait training + IM	18/15	6	+
Dickstein et al (2013)	>12	23	Balance, Gait	10mWT, FRSE	MI	12/9	4	+/N
Ferreira et al (2011)	≥3	10	UL	BIT, FIM	Physical practice + MI	10/15	5	+
Grabherr et al (2015)	>3	25	UL	RT, MT	Physiotherapy + MI	?/30	13 days	+
Hwang et al (2010)	>12	24	Balance, Gait	BCS, BBS, DGI, EFAP, and kinematic gait	Physiotherapy + MI with video	20/30	4	+
Letswaart et al (2011)	≤3	121	ADL, UL	ARAT, BI	Exercises + mirror therapy + MI with video and object	12/45	4	N
Kim et al (2015)	?	24	UL	FMUL, WMFT	Physiotherapy + MI	12/30	4	+
Kim et al (2015)	?	26	LL/Gait	TUG, ASW	Physical practice + MI	16/15	4	+
Lee et al (2011)	<6	24	Gait	Gait speed (cm/s)	Gait training + MI	18/30	6	+
Lee et al (2015)	<12	36	Balance, Gait	Korean BBS, TUG	Proprioception training + MI	40/5	8	+
Liu et al (2004)	<1	46	ADL, UL	CTT, FM,	Physiotherapy + MI	15/?	3	+
Liu et al (2009)	<1	34	ADL, Gait, and UL	PT, FM	Physiotherapy + MI	15/30	3	+
Liu et al (2009)	<1	35	ADL	PT	Physiotherapy + MI	15/?	3	+
Liu et al (2014)	≤3	20	UL	ARAT, number of activated voxels by FMR	Physical practice + MI after video	20/45	4	+
Malouin et al (2009)	>12	20	LL	VF	Physical practice + MI	12/?	4	+
Muller et al (2007)	<3	17	UL	JTHFT and grip force	Physiotherapy + MI	20/30	4	+
Nilsen et al (2012)	>12	19	UL	FMUL, JTTHF, COPM	Occupational therapy + MI	12/?	6	+
O'Brien et al (2011)	≤6	10	UL	ME, MT	Physiotherapy + MI with video	?	?	+
Oostra et al (2015)	<6	44	LL/Gait	FMLL, 10mWT	Physiotherapy + occupational therapy + MI	30/30	6	+
Page (2000)	>12	16	UL	FMUL	Occupational therapy + MI	12/20	4	+
Page et al (2005)	>12	11	UL	MAL, ARAT	Physiotherapy + MI with audio	12/30	6	+
Page et al (2007)	>12	32	UL	FMUL, ARAT	Physiotherapy + MI with audio	12/30	6	+
Page et al (2011)	>12	29	UL	FMUL, ARAT	Physiotherapy + MI with audio	30/20; 40; 60	10	N
Park et al (2015)	<12	30	UL	LBT, SCT	Physiotherapy + MI	20/10	4	+/N
Riccio et al (2010)	<3	36	UL	MOI, AFT	Physiotherapy + occupational therapy + MI	15/60	3	+
Schuster et al (2012)	≤3	39	Balance	TP	Physiotherapy + MI	6/?	2	+
Sun et al (2013)	>6	18	UL	FMUL, number of activated voxels by FMR	Physiotherapy + Occupational therapy + MI	20/30	4	+
Timmermans et al (2013)	<1	42	UL	FMUL, WMFT	Physiotherapy + MI	?/10	6	+/N
Verma et al (2011)	<3	30	Gait	RVGA, speed, 6MWT	Task-oriented circuit class training + MI	14/15	6	+
Welfringer et al (2011)	<6	30	UL	NT	Physiotherapy + MI	24/30	3	+

Abbreviations: AFT, Arm Functional Test; ARAT, Action Research Arm Test; ASW, affect side weight; BBS, Berg Balance Scale; BCS, Berg Confidence Scale; BI, Barthel Index; BIT, Behavioral Inattention Test; COPM, Canadian Occupational Performance Measure; CTT, Colour Trails Test; DGI, Dynamic Gait Index; EFAP, Emory Functional Ambulation Profile; FIM, Functional Independence Measure; FMLL, Fugl-Meyer Lower Limb subscale; FMUL, Fugl-Meyer Upper Limb subscale; FRM, functional resonance magnetic; FRSE, fall-related self-efficacy; FRT, Functional Reach Test; FSST, Four Square Step Test; JTTHF, Jebsen Taylor Test of Hand Function; LBT, line bisection test; LL, lower limb; MAL, motor activity log; ME, movement extension; MI, mental imagery; MOI, Motricity Index; MT, movement task; MT, movement time; NT, neglect tests; NHPT, Nine Hole Peg Test; RMI, Rivermead Mobility Index; PT, performance task; RT, recognition task; RVGA, Rivermead Visual Gait Assessment; SCT, Star Cancellation Test; 6MWT, Six-Minute Walk test; 10mWT, 10-Meter Walk Test; TP, time performance; TUG, Timed Up and Go; UL, upper limb; VF, vertical forces; WMFT, Wolf Motor Function Test.

Table 2. Description of the Cochrane Back Review Scale of Methodological Quality

Author (Year)	A	B	C	D	E	F	G	H	I	J	K	Score
Verma et al (2011)	+	+	+	−	−	+	+	+	+	+	+	9
Braun et al (2012)	+	+	+	−	−	+	+	−	+	+	+	8
Liu et al (2004)	+	+	+	−	−	+	+	+	+	+	−	8
Liu et al (2009)	+	+	+	−	−	+	+	+	+	+	−	8
Letswaart et al (2011)	+	+	+	−	−	+	−	+	+	+	+	8
Schuster et al (2012)	+	+	−	−	−	+	+	+	+	+	+	8
Riccio et al (2010)	+	+	−	−	−	+	+	+	+	+	+	8
Nilsen et al (2012)	+	+	+	−	−	+	+	+	?	+	−	7
O'Brien et al (2011)	−	+	+	−	−	+	+	+	+	+	−	7
Page et al (2011)	+	+	+	−	−	+	+	+	?	+	−	7
Welfringer et al (2011)	+	+	+	−	−	+	+	−	+	+	−	7
Ferreira et al (2011)	?	?	+	−	−	+	+	+	+	+	−	6
Timmermans et al (2013)	+	?	+	−	−	+	+	−	+	+	−	6
Liu et al (2009)	−	?	−	−	−	+	+	+	+	+	−	5
Cho et al (2012)	+	+	?	−	−	+	−	−	+	+	−	5
Malouin et al (2009)	?	?	+	−	−	+	+	+	?	+	−	5
Liu et al (2014)	−	?	+	−	−	+	+	+	?	+	−	5
Page (2000)	?	?	+	−	−	?	+	+	+	+	−	5
Park et al (2015)	+	+	?	−	−	+	+	−	?	+	−	5
Sun et al (2013)	?	?	+	−	−	+	+	−	+	+	−	5
Hwang et al (2010)	−	−	?	−	−	?	+	+	+	+	−	4
Oostra et al (2015)	−	?	−	−	−	?	+	+	+	+	−	4
Kim et al (2015)	?	?	?	−	−	?	+	+	+	+	−	4
Page et al (2007)	−	?	?	−	−	+	+	+	?	+	−	4
Page et al (2005)	+	?	?	−	−	+	+	−	?	+	−	4
Dickstein et al (2013)	−	?	?	−	−	+	−	−	+	+	−	3
Lee et al (2015)	?	?	?	−	−	?	+	+	?	+	−	3
Lee et al (2011)	+	?	?	−	−	?	+	−	−	+	−	3
Grabherr et al (2015)	−	?	?	−	−	−	+	+	?	+	−	3
Muller et al (2007)	−	?	+	−	−	?	+	+	?	+	−	3
Kim et al (2015)	?	?	?	−	−	?	+	−	?	+	−	2
Bae et al (2015)	−	−	−	−	−	−	+	−	?	+	−	2

Abbreviations: A, randomization method; B, allocation concealed; C, similar baseline; D, patient blinded; E, provider blinded; F, assessor blinded; G, cointervention avoided; H, acceptable compliance; I, acceptable dropout; J, timing of outcome assessment similar; K, intention-to-treat analysis.

describe conflicts of interest in statement.[¶¶] Tables containing the conflicts of interest and financing of the studies included and the PEDro and Cochrane ratings are provided as supplementary material (see Online PDF, Supplementary Digital Content 2, http://links.lww.com/JNPT/A191).

META-ANALYSIS

In the meta-analysis, 9 studies were excluded from the UL subgroup for not containing the necessary data on statistical tests (mean and standard deviation). Two studies were excluded from each of the other subgroups, ADL,[13,37] Balance,[12,48] and LL/Gait,[13,38] for the same reason[13] excluded studies.[13] On the calculation of effect size, a positive sign indicated when the experimental group showed greater effects than the control group, based on the particulars of the specific outcome measures used by each study.

Figure 2 illustrates the outcomes of Analysis 1. In these forest plots, lines that fall on the right-side of the graph, represent participants who received the intervention in one particular study and showed significant positive changes compared to control participants. The "black diamonds" are the average effect size of all trials and should be interpreted the same way. Significant differences were found between the MI group and the control group for 3 outcomes: Balance (SMD = 1.78 [95% CI, 0.47-3.10], $P = 0.0008$, $I^2 = 93\%$) (Figure 2A), LL/Gait (SMD = 0.70 [95% CI, 0.23-1.17], $P = 0.003$, $I^2 = 82\%$) (Figure 2C), and UL (SMD = 0.36 [95% CI, 0.16-0.55], $P = 0.0004$, $I^2 = 30\%$) (Figure 2D). The outcome of the ADL group was not significant (SMD = 0.35 [95% CI, −0.24 to 0.95], $P = 0.24$, $I^2 = 79\%$) (Figure 2B). However, the studies were highly heterogeneous, as evidenced by the I^2 values.

In Analysis 2, statistically favorable differences were found for the MI group relative to the control group on the balance assessment using the Functional Reach Test (FRT) (MD = 8.82 [95% CI, 6.16-11.49], $P < 0.00001$, $I^2 = 0\%$) but not the Berg Balance Scale (MD = 4.98 [95% CI, −4.36 to 14.32], $P = 0.30$), $I^2 = 93\%$). On the assessment of performance in gait, a significant difference was observed on the assessment by the TUG (MD = −4.43 [95% CI, −7.66 to −1.19], $P = 0.007$, $I^2 = 57\%$) and gait speed (MD = 0.49 [95% CI, 0.09-0.89], $P = 0.02$, $I^2 = 0\%$) but not for the 10-Meter Walk Test (MD = 0.06 [95% CI, −3.38 to 3.50], $P = 0.97$, $I^2 = 49\%$). Regarding the instruments used in the studies for assessing motor performance of the UL group, a statistical difference was detected for the ARAT (MD = 4.80 [95% CI, 2.47-7.13], $P < 0.0001$, $I^2 = 0\%$) and the Fugl-Meyer Upper Limb (FMUL) subscale (MD = 3.94 [95% CI, 0.76-7.12], $P = 0.02$, $I^2 = 0\%$), along with a lower heterogeneity.

[¶¶]References 9, 11, 13, 15, 27, 29-34, 37-47, 50.

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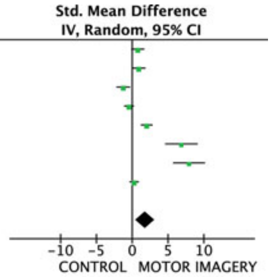
Study or Subgroup	MOTOR IMAGERY Mean	SD	Total	CONTROL Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bae 2015 a	44.2	12.6	10	34.9	10.1	10	13.2%	0.78 [−0.14, 1.70]
Bae 2015 b	32.4	7.1	10	25.9	6.5	10	13.2%	0.91 [−0.02, 1.85]
Bae 2015 c	18.8	7.1	10	27.9	6.9	10	13.1%	−1.24 [−2.22, −0.27]
Braun 2012 a	28.6	15	16	35.28	14.4	18	13.6%	−0.44 [−1.13, 0.24]
Braun 2012 b	37.5	3	18	28.1	5.7	18	13.4%	2.02 [1.20, 2.84]
Hawng 2009 a	54.69	1.44	13	40.73	2.45	11	9.9%	6.86 [4.59, 9.13]
Hwang 2009 b	86.15	3.45	13	50.97	4.84	18	10.0%	7.93 [5.70, 10.16]
Lee 2015	42	8	18	40.17	4.82	18	13.6%	0.27 [−0.39, 0.93]
Total (95% CI)			**108**			**113**	**100.0%**	**1.78 [0.47, 3.10]**

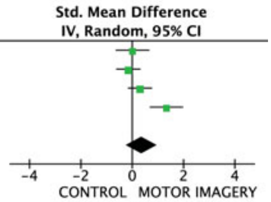
Heterogeneity: $Tau^2 = 3.20$; $Chi^2 = 106.42$, df = 7 ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: Z = 2.66 (P = 0.008)



B

Study or Subgroup	MOTOR IMAGERY Mean	SD	Total	CONTROL Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Braun 2012 e	15	4.5	18	14.94	5.5	18	23.2%	0.01 [−0.64, 0.67]
Ietswaart 2011 Ia	16.23	4.13	39	16.84	3.75	31	26.7%	−0.15 [−0.62, 0.32]
Ietswaart 2011 IIa	16.23	4.13	39	14.87	4.79	32	26.8%	0.30 [−0.17, 0.77]
Liu 2004	5.3	1	26	4	0.9	20	23.3%	1.33 [0.68, 1.98]
Total (95% CI)			**122**			**101**	**100.0%**	**0.35 [−0.24, 0.95]**

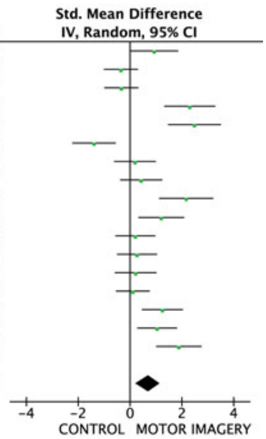
Heterogeneity: $Tau^2 = 0.29$; $Chi^2 = 14.00$, df = 3 ($P = 0.003$); $I^2 = 79\%$
Test for overall effect: Z = 1.16 (P = 0.24)



C

Study or Subgroup	MOTOR IMAGERY Mean	SD	Total	CONTROL Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bae 2015 d	−14.7	4.7	10	−19.5	5.2	10	5.6%	0.93 [−0.01, 1.86]
Braun 2012 c	8.06	4.2	18	9.5	3.8	18	6.3%	−0.35 [−1.01, 0.31]
Braun 2012 d	−16.25	6.3	18	−14.08	6.3	18	6.3%	−0.34 [−1.00, 0.32]
Cho 2012 a	−13.2	2.2	15	−20.7	4	13	5.5%	2.30 [1.32, 3.29]
Cho 2012 b	17.6	1.3	15	12	2.9	13	5.4%	2.48 [1.46, 3.51]
Cho 2012 c	−16	2.7	15	−12	2.9	13	5.9%	−1.39 [−2.23, −0.55]
Dickstein 2013	0.59	0.39	13	0.52	0.31	11	6.0%	0.19 [−0.62, 1.00]
Hwang 2009 c	0.54	0.23	13	0.44	0.22	11	5.9%	0.43 [−0.39, 1.24]
Hwang 2009 d	17.92	2.23	13	11.64	3.36	11	5.3%	2.16 [1.12, 3.21]
Hwang 2009 e	−67.38	17.72	13	−91.03	20.37	11	5.7%	1.20 [0.32, 2.09]
Kim 2015 1a	17.28	6.92	13	15.89	6.33	13	6.0%	0.20 [−0.57, 0.97]
Kim 2015 1b	−19.39	7.08	13	−21.29	6.67	13	6.0%	0.27 [−0.51, 1.04]
Lee 2011	55.68	17.72	13	51.5	19.73	11	5.9%	0.22 [−0.59, 1.02]
Lee 2015	−27.06	9.28	18	−27.98	7.68	18	6.3%	0.11 [−0.55, 0.76]
Verma 2011 a	−20.13	6.42	15	−30.53	9.52	15	6.0%	1.25 [0.45, 2.04]
Verma 2011 b	0.58	0.14	15	0.43	0.14	15	6.0%	1.04 [0.27, 1.81]
Verma 2011 c	199.2	17.12	15	111.7	61.62	15	5.8%	1.88 [1.00, 2.76]
Total (95% CI)			**245**			**229**	**100.0%**	**0.70 [0.23, 1.17]**

Heterogeneity: $Tau^2 = 0.79$; $Chi^2 = 90.34$, df = 16 ($P < 0.00001$); $I^2 = 82\%$
Test for overall effect: Z = 2.94 (P = 0.003)



D

Study or Subgroup	MOTOR IMAGERY Mean	SD	Total	CONTROL Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Braun 2012 f	−25	11.3	14	−28.41	12.9	17	5.5%	0.27 [−0.44, 0.98]
Braun 2012 g	−24.86	11.9	14	−23.64	10.9	14	5.1%	−0.10 [−0.85, 0.64]
Ietswaart 2011 Ib	38.15	36.07	39	34.55	34.8	31	9.1%	0.10 [−0.37, 0.57]
Ietswaart 2011 Ic	31.51	20.68	39	32.87	20.76	31	9.1%	−0.06 [−0.54, 0.41]
Ietswaart 2011 IIb	38.15	36.07	39	34.32	33.8	32	9.2%	0.11 [−0.36, 0.58]
Ietswaart 2011 IIc	31.51	20.68	39	30.38	20.53	32	9.2%	0.05 [−0.41, 0.52]
Kim 2015 2a	36.08	9.9	12	31	5.33	12	4.4%	0.62 [−0.21, 1.44]
Kim 2015 2b	51	21.56	12	40.17	25.3	12	4.5%	0.44 [−0.37, 1.26]
Liu 2014	30.1	17.43	10	19.3	15.12	10	3.8%	0.63 [−0.27, 1.54]
Page 2000	29.97	4.1	8	26.89	5.4	8	3.2%	0.61 [−0.40, 1.62]
Page 2005	43.8	3.09	6	38.7	1.2	5	1.5%	1.91 [0.36, 3.46]
Page 2007 a	39.75	6.86	16	36.75	10.74	16	5.6%	0.32 [−0.37, 1.02]
Page 2007 b	25.81	11.29	16	17.69	13.75	16	5.4%	0.63 [−0.08, 1.34]
Park 2015	−5.1	1.8	15	−7.2	1.6	15	4.7%	1.20 [0.41, 1.99]
Park 2015 a	53.5	2.3	15	53.3	2.8	15	5.4%	0.08 [−0.64, 0.79]
Riccio 2010	−34.61	8.99	18	−48.24	13.34	18	5.4%	1.17 [0.46, 1.89]
Sun 2013	39.78	14.03	9	25.33	22.63	9	3.4%	0.73 [−0.23, 1.69]
Welfringer 2011	9.6	18.5	15	6.5	16.2	15	5.4%	0.17 [−0.54, 0.89]
Total (95% CI)			**336**			**308**	**100.0%**	**0.36 [0.16, 0.55]**

Heterogeneity: $Tau^2 = 0.05$; $Chi^2 = 24.41$, df = 17 ($P = 0.11$); $I^2 = 30\%$
Test for overall effect: Z = 3.57 (P = 0.0004)

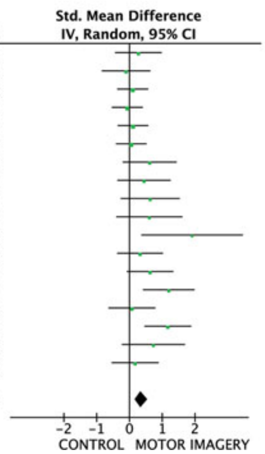


Figure 2. Overall meta-analysis of each subgroup including studies of all methodological qualities (see the text for explanation of figures). (A) Balance. (B) Activities of Daily Living (ADL). (C): Lower Limb (LL)/Gait. [a]To adjust for the different scale directions, values of scales that report improvement with decreasing values were multiplied by −1. (D). Upper Limb (UL). [a]To adjust for the different scale directions, values of scales that report improvement with decreasing values were multiplied by −1.

In Analysis 3, for the balance outcome was not possible because only one study, by Braun et al,[10] had a quality score of 6 or more on the Cochrane scale. However, all the studies included in this review that investigated the effects of MI on activities of daily living had adequate methodological quality and the Analysis 3 found no significant difference between the intervention group and the control group (SMD = 0.35 [95% CI, −0.24 to 0.95], $P = 0.24$, $I^2 = 79\%$) (Figure 3A). Similarly, for the other outcomes, no significant differences were found between the experimental group (MI) and the control group: LL/Gait (SMD = 0.67 [95% CI, −0.20 to 1.54], $P = 0.13$, $I^2 = 85\%$) and UL (SMD = 0.17 [95% CI, −0.07 to 0.40], $P = 0.16$, $I^2 = 27\%$) (Figures 3B and 3C).

DISCUSSION

The findings of our systematic review and meta-analysis revealed a wide range of MI protocols and a large amount of heterogeneity in the methodological quality of the studies. The study samples included participants at different times after stroke and used a large variety of assessment methods. While the studies included in the systematic review showed predominantly positive results of the MI interventions, the overall meta-analysis of studies (which excluded lower-quality studies) found no significant differences compared with controls (Analysis 3). However, when including low-quality studies (Analysis 1) or on subanalyses (Analysis 2), positive results were found for both lower limb/gait (shorter performance time on the TUG and increased gait speed) and the upper limb (improved motor performance on the ARAT and FMUL) as well as balance (balance gains on the FRT).

Our results are comparable with those of the previous meta-analyses, which found differences for the ARAT subanalysis.[6,20] When only high-quality studies were included, our results are also consistent with another meta-analysis that found no changes in upper limb function in the overall analysis.[18] Akin to previous meta-analyses,[6,18,20] a relatively small number of studies compared with those initially identified can be included in the final analysis when methodological quality and date availability are taken into account.

With regard to MI protocol used, it was not possible to determine the number of repetitions of imagery applied for the movements or specific tasks to be imagined in the studies because only the total duration of the intervention was reported. Given that MI requires orientation time and a facilitation strategy for the movement or task to be imagined, which in some studies led to the use of videos or audio, failure to describe the time or exact number of repetitions of imagery performed by the volunteer hampers the development of more structured protocols for use of MI.

Beyond the number of repetitions, another noteworthy deficit of the studies is the lack of monitoring of participants during imagery of the movements. Although MI is a cognitive task that requires concentration and whose training can produce autonomic changes,[51] the studies dedicated little attention to monitoring parameters such as heart rate and respiration frequency of participants during MI, which could demonstrate

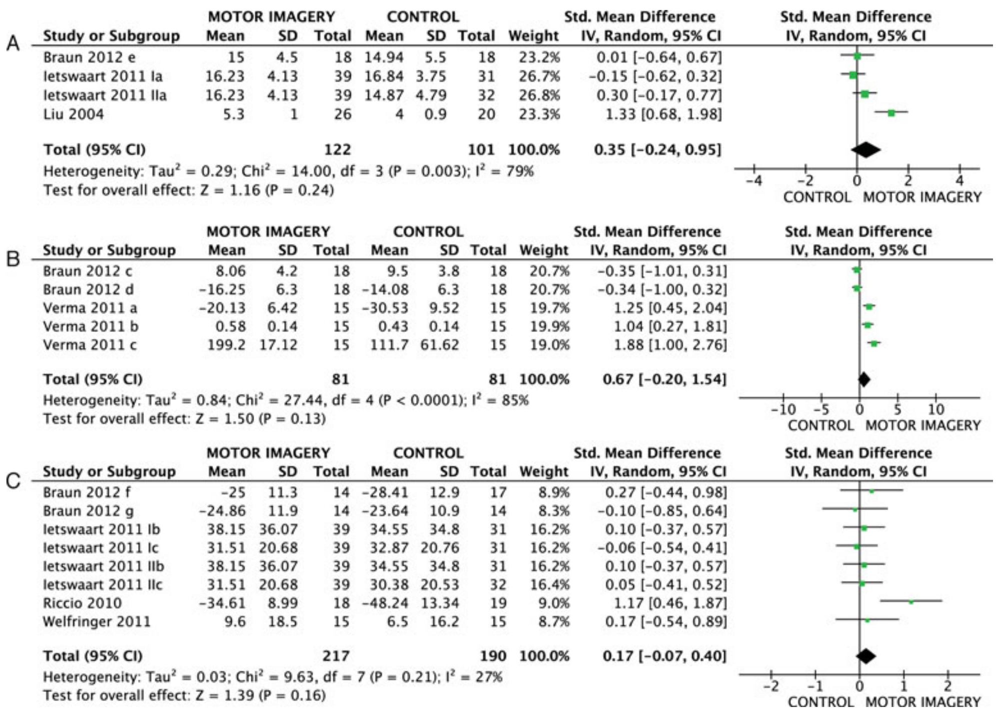


Figure 3. Meta-analysis of only quality studies (see the text for explanation of figures). A: Balance. Only Braun et al[10] have a quality of 6 or more on the Cochrane scale, precluding meta-analysis. B: Activities of Daily Living (ADL). C: Lower Limb (LL)/Gait. [a]To adjust for the different scale directions, values of scales that report improvement with decreasing values were multiplied by −1. D: Upper Limb (UL). [a]Since we have scales with different directions, some means were multiplied by −1 to correct for scale direction.

whether the imagery was being performed correctly. In view of evidence showing differences in imagery ability among individuals irrespective of neurologic impairments,[52] and that synaptic compromise can affect imagery ability,[53] it is notable that not all studies took this criterion into account by using specific questionnaires. This fact might explain the neutral results of some studies and also the findings of the studies analyzed in the present meta-analysis.

With regard to time elapsed since stroke, our data were derived from studies that included participants of all phases poststroke, although most were in the acute and subacute phases. The predominance of studies in the acute and subacute phases was also found in the meta-analysis by Cha et al[20] investigating the effect of MI combined with functional task training. In previous systematic reviews, such as that of García Carrasco and Aboitiz Cantalapiedra[17] and meta-analyses including those by Barclay-Goddard et al,[16] Kho et al,[6] and Machado et al,[18] the studies of participants in the chronic phase of stroke predominated.

With regard to the quality of the studies, methodological weaknesses still prevail in this area, where 59.3% (19) of the studies failed to attain an adequate score on the Cochrane scale. Some outcomes such as balance were associated with lower-quality studies than other outcomes.[9,34] Although evidence exists showing that the PEDro scale provides a better measure of methodological quality than the Jadad scale[54] and the former has been used in previous meta-analyses and systematic reviews, we chose the Cochrane scale over other scales because it is less influenced by the double-blinding issue.

Our findings reveal that there remains a lack of standardization in the MI study protocols and other aspects of this area of study, which may be responsible for some of the conflicting results between trials and meta-analyses. Another unresolved question is the timepoint at which MI should be introduced. Several trials started MI in early phases poststroke whereas others included participants in the chronic phase, which could also be responsible for differences in findings. Likewise some meta-analyses have included more studies of participants with acute/subacute stroke than others, depending on their search methods and inclusion and exclusion criteria. Motor imagery may have more value in acute and subacute stroke, but at present, there is insufficient evidence to determine this. Overall, the evidence suggests that MI may have value for persons recovering from stroke, particularly for specific outcomes. However, a larger number of rigorous studies are needed.

LIMITATIONS

The present study has several limitations including the small number of studies included in the analysis. The analysis included few studies because methodological quality and data availability were inclusion criteria, leading to the exclusion of all studies with measures investigating balance. Another limitation was the selection of studies whose abstract or title were in English, where the key word/descriptors chosen for the search may have excluded studies that met the other inclusion criteria from the analysis. Finally, some article databases such as EMBASE were not searched, where this may have led to the exclusion of some studies.

CONCLUSIONS

There is a high heterogeneity among studies investigating MI for recovery of persons poststroke, in terms of both protocols and intervention time. The majority of studies included in the systematic review showed benefits of the MI, albeit with a large proportion of low-quality studies. The meta-analysis of all studies regardless of quality revealed significant differences on overall analysis for 3 outcomes (balance, lower limb/gait, and upper limb). However, when only high-quality studies were included, no significant difference between the MI and control groups was found. On the subgroup analysis, MI was associated with shorter performance time for the TUG, increased gait speed, improved motor performance on the ARAT and FMUL, as well as balance gains on the FRT, relative to control groups. Further high-quality studies and greater standardization of these interventions are needed in this field of research.

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