UCLouvain

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Differences in motor imagery abilities in patients with neurological conditions compared to healthy individuals:

A systematic review and meta-analysis

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Année académique: 2023-2024
Master en kinésithérapie et réadaptation [60.0] - KINE2M

Acknowledgements

We would like to express our deep gratitude to God and to several people who have contributed significantly to the completion of this work.

First, we would like to thank our promoter, Professor Robert HARDWICK for his availability, his advice, and the constructive feedback on this end-of-study work.

We would also like to thank our co-promoter Dr Marcos MORENO VERDÚ for his availability, his expertise sharing and all support that were very enriching in the completion of this work.

We would also like to thank Mrs. Sophie Patris for her time and advice in developing our search strategy.

Finally, we are very grateful to our families who, despite the distance, support us and give us courage in the face of adversity. We would like to dedicate this work to them.

I, Imaann, would particularly like to dedicate this work to my mother.

Abstract

Introduction: Motor imagery (MI) is a therapeutical option in neurorehabilitation but there is no conclusive evidence about its effectiveness. This could be because MI ability is altered after damage to the central nervous system.

Aim: To investigate whether there is a difference in MI ability between healthy individuals and people with central neurological conditions involving altered motor networks.

Methods: We searched 6 electronic databases up to February 2024. Studies comparing people with stroke, Parkinson's disease (PD), Multiple Sclerosis (MS), Traumatic Brain Injury (TBI) and Cerebral Palsy (CP) with healthy controls (HCs) were included. The selection process and Risk of Bias assessment (by the JBI critical appraisal checklist) was done independently by 2 reviewers. MI ability assessed through questionnaires, mental chronometry, and mental rotation tasks was the outcome extracted. Quantitative and qualitative analyses were used per MI domains and per conditions.

Results: Fifty-nine studies were included. Analysis revealed some evidence for a preserved MI generation ability overall, while mental transformation ability was likely impaired in stroke but preserved in PD and MS. Despite the high heterogeneity in mental timing measures, the trend was toward impairment for this ability.

Conclusion: Compared to HCs, some aspects of MI ability seemed to be preserved in these neurological conditions. The high heterogeneity in mental chronometry measures and the lack of studies for some conditions restricted the summary of evidence.

List of abbreviations/acronyms

CP: Cerebral palsy

FLJT: Foot Laterality Judgment Task

HC: Healthy Controls

HLJT: Hand Laterality Judgment Task

JBI: Joanna Briggs Institute's checklist

KVIQ-10: Kinesthetic and Visual Imagery Questionnaire-10 items

KVIQ-20: Kinesthetic and Visual Imagery Questionnaire-20 items

MI: Motor Imagery

MIQ: Movement Imagery Questionnaire

MIQ-3: MIQ-third revised version

MIQ-R: MIQ-revised version

MIQ-RS: MIQ-second revised version

MS: Multiple Sclerosis

PICO(S) criteria: Population, Intervention, Comparison, Outcome, Study design

PD: Parkinson's disease

RCT: Randomized controlled Trial

RoB: Risk of Bias

RT: Reaction Time

TBI: Traumatic Brain Injury

VMIQ: Vividness of Movement Imagery Questionnaire

VMIQ-2: VMIQ second version

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1 INTRODUCTION

Motor imagery (MI) is the mental representation or cognitive rehearsal of a motor act or movement in the absence of any overt motor output (Jeannerod, 2001; Williams et al., 2015). It differs from the general term mental imagery in that it is a body-centred process which involves not only classic visual imagery modality but also kinesthetic imagery. It is a cognitive strategy that can facilitate learning and relearning, increase muscle strength and performance (Williams et al., 2015). The kinesthetic modality implies to imagine real motion (Daprati et al., 2010). The visual modality refers to visualise the action without the sensory feedback (Munzert et al., 2009). In more practical terms, imagining the feeling of squeezing a ball in your hand and related sensory feedback belong to kinesthetic imagery, whereas imagining seeing yourself squeezing a ball with your hand pertains to visual imagery.

Over the past few decades, researchers have become interested in the mechanisms behind MI and its application in multiple disciplines like cognitive neuroscience and neurorehabilitation (Collet et al., 2011; Hurst & Boe, 2022). This interest stems in large part from evidence showing MI can drive acquisition of simple and complex motor skills (Ladda et al., 2021; Schuster et al., 2011). Actually, neuroimaging findings provided evidence that MI and physical practice are functionally equivalent, i.e., recruit overlapping brain regions within the brain motor networks underlying motor preparation and execution (Di Rienzo et al., 2014; Wong et al., 2013).

The ability to mentally imagine motion is a complex cognitive process and a multidimensional skill that involves not just the way we generate images, but also how we maintain images over time. The existing models agree on dividing mental imagery into three main processing components: namely generation, maintenance and transformation/manipulation (Cumming & Eaves, 2018; Kraeutner et al., 2020). Inspection is an additional process not covered in the above-mentioned definition that also help us to understand the nature of imagery ability (Suica et al., 2022). The concepts of internal (first-person view) and external (third-person view) perspective complete the shape of MI, the former being exclusively associated with kinesthetic imagery (Daprati et al., 2010; Suica et al., 2022). A hierarchical model to explain the expanded structure and nature of MI is presented in Figure 1.

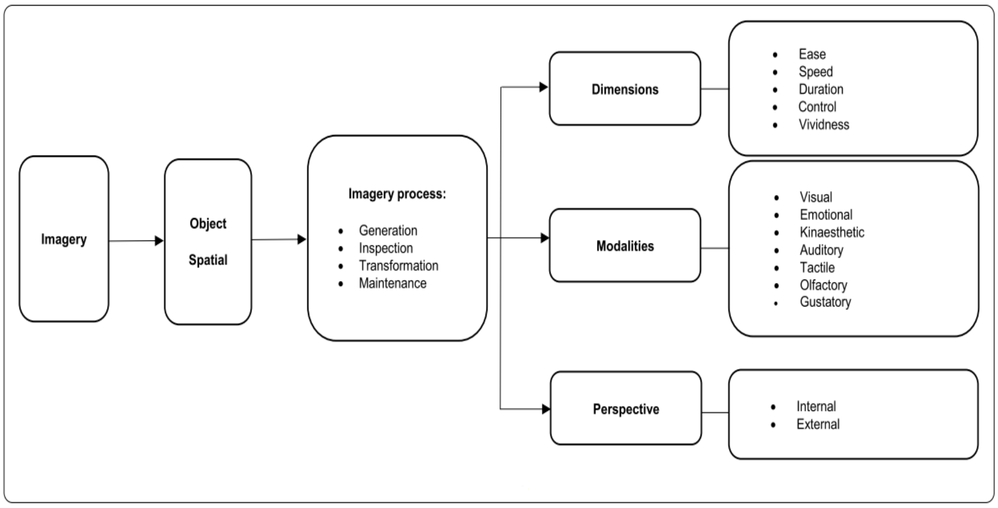


Fig. 1. A model for multidimensional and multimodal structure of imagery ability (Suica et al., 2022). Note that only visual and kinesthetic modalities are related to motor imagery.

Generation involves creating an image based on retaining sensory information or stored information in long-term memory in the absence of perceptual stimuli, whereas inspection consists of scanning the whole or parts of an image, interpreting its patterns and extracting information. This act of inspecting an image can lead to create further details of the imagined task or can be used to check if there is a match between the generated and desired image. Transformation or manipulation requires changing either the content (what is imagined, e.g. skills, strategies, objectives) or the characteristics (how the imagined content is experienced, e.g. layout, angle, modality, perspective) of an image. Maintenance illustrates the ability to sustain these processes over time (time-consuming generation, manipulation and inspection) to achieve the desired results (Cumming & Eaves, 2018).

Therefore, MI ability is not a static and uniform capacity, but rather a dynamic and nuanced skill. In fact, like any other skill, it could vary both within and between individuals (Floridou et al., 2022; Guillot et al., 2008), and performance in this cognitive process can fluctuate depending on factors such as age, gender and experience with the task (Orlandi et al., 2020; Schott, 2012; Subirats et al., 2018).

Moreover, since it is a cognitive skill, damage to the central nervous system could potentially cause MI ability deficits (Kerry et al., 2016).

As a covert process that can only be truly observed by the imager, a challenge for researchers has been to measure imagery ability in a valid and reliable way. For MI, both subjective and objective measurement approaches are available and can be divided into biological (neurophysiological) and behavioural measures (Collet et al., 2011). Neurophysiological measures can tap MI more objectively using methods to assess its neural correlates (Helm et al., 2015; Hétu et al., 2013; Lorey et al., 2013; Toriyama et al., 2018). Behavioural measures involve gathering information about explicit imagery experiences using mental chronometry or questionnaires (Malouin et al., 2008b; Malouin et al., 2007) but also about implicit imagery using mental rotation tasks (Boonstra et al., 2012).

At present, the relevance and use of MI in rehabilitation is controversial. Some studies support that MI have beneficial effects in the rehabilitation of neurological disorders like stroke or neurodegenerative diseases, (Seebacher et al., 2023; Winstein et al., 2016) but meta-analyses have not reported conclusive results (Braun et al., 2013; Singer et al., 2024). This uncertainty may be due to differences in MI abilities between people with neurological disorders and healthy individuals, as brain lesions and exposure to various factors (e.g. cognitive impairment, cognitive fatigue, severe disability) could influence MI ability (Kerry et al., 2016; Seebacher et al., 2023). It has also been suggested that an adjustment of MI ability to the present state of the motor system may occur after neurological insult (Di Rienzo et al., 2014). Indeed, as MI uses a neural network closely matching the one of movement execution (Hardwick et al., 2018), pathologies that impair motor execution could potentially impair MI as well.

In the light of all the above information, it seems pertinent to increase our knowledge about MI ability in neurological disorders to help clinicians make better use of MI training programmes. Particularly, it is crucial to account for potential differences in MI ability in people with neurological diseases, as this could influence the extent to which therapeutical interventions based on MI training can be implemented. To our knowledge, there are no reviews summarizing the evidence on MI ability changes in multiple neurological diseases and multiple imagery measures. Furthermore, individual studies are underpowered as they typically have very limited sample sizes, and therefore a meta-analysis aimed at this goal would be relevant to achieve the desired statistical precision to draw more robust findings. Hence, our goal was to investigate whether there is a difference in MI ability between healthy individuals and people with central neurological conditions involving altered motor networks.

This work is part of a larger study investigating MI ability in a more diverse population of neurological conditions and so it is focused on the most prevalent ones namely stroke, Parkinson's disease (PD), Multiple Sclerosis (MS), Traumatic Brain Injury (TBI) and Cerebral Palsy (CP).

2 METHODS

2.1 Study design and pre-registration

The protocol for this review was pre-registered with the International Prospective Register of Systematic Reviews (registration number CRD42024485513). The present systematic review was written and reported using the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) guidelines (Page et al., 2021) (Appendix 1).

2.2 Research question and selection criteria

Our research question was “Does motor imagery ability differ in people suffering from neurological disorders and chronic pain compared to healthy individuals?”. The PICO(S) criteria method that defined the research question is illustrated below in Table 1.

Table 1: PICO(S) criteria (Population, Intervention, Comparison, Outcome, Study design)

CRITERIA	MAIN CONCEPTS	MAIN KEYWORDS
POPULATION	People with neurological conditions; People with chronic pain	“central nervous system disease”; "chronic pain"
INTERVENTION	Motor imagery (assessment)	"movement imagery"; “action imagery”
COMPARATOR	Healthy individuals	“normal subjects”; “healthy subjects”
OUTCOMES	Motor imagery ability	-
STUDY DESIGN	Observational, Experimental	“case control studies”; “controlled study”; “matched case control”; “experimental study”

To answer this question the population of interest was: people with acquired neurological conditions like stroke; TBI; spinal cord injury; neurodegenerative diseases (PD, Alzheimer’s disease, MS, amyotrophic lateral sclerosis); pediatric diseases (e.g. CP) and chronic pain (e.g. complex regional pain syndrome, phantom pain, low back pain).

The inclusion criteria were the following:

- Original articles, full-text documents, written in English and published from inception up to February 2024 in peer-reviewed journals.
- Studies which assessed MI under its multiple dimensions and domains by standardized subjective and/or objective measures (behavioural/neurophysiological methods).
- Studies which compared the performance of people with neurological disorders and chronic pain conditions to healthy controls (HCs), regardless of their design.
- Observational studies (case-control or cross-sectional design), or experimental studies (Randomized and non-Randomized Controlled Trials) with baseline/pre-intervention comparisons between people with neurological disorders and HCs.

No restrictions on publication dates or sociodemographic variables (e.g. age, gender, race, education level, handedness) were applied.

No restrictions on any clinical characteristics were applied, including time with disease, severity, motor and/or non-motor symptoms, disease's evolution stage, regional distribution or type of motor deficits, etc. These variables were considered as moderators if studies sufficiently and consistently reported them.

Exclusion criteria were:

- Non-scientific papers, study protocols and articles with full-text not available.
- Studies not related to MI assessment.
- No outcome measures of interest.
- Outcome measures were not compared to HCs.
- No assessment methods of interest (neurophysiological measures, questionnaires/other self-reported MI ability measure, mental chronometry and mental rotation tasks).

For the present work which is a part of the presented/principal study, **we restricted the population of interest** to stroke, PD, TBI, MS and CP in order to adapt the number of eligible records to the Master's degree thesis. Moreover, we only consider studies with behavioural MI ability measures, excluding neurophysiological studies, for the same reason. Since, the more focused research question was “Does motor imagery ability differ in people suffering from **neurological disorders** compared to healthy individuals?”

2.3 Searches: information sources, dates of searches and search strategy

Systematic searches using queries were performed in Embase, PubMed, Cochrane Library, Scopus, CINAHL, PsycINFO through the electronic library access of “Université Catholique de Louvain” from December 2023 up to February 2024. A manual search was made in May 2024 (see below for details).

We first established a complete query in Embase. Then we introduced it into the “Systematic Review-ACCELERATOR-polyglot search” tool (SR-Accelerator) to obtain a translation of the query upon the other databases. After that, we manually adapted the obtained translations in order to get the appropriate thesaurus terms and intern search strategy language related to each database. For the manual search we included records found in a recent systematic review on MI ability in a stroke population which had included papers that met our inclusion criteria (Santoro et al., 2019).

The search strategy was defined to retrieve all records that included the main concepts of “motor imagery”, “neurological condition” (note that here, we considered all neurological conditions mentioned as population of interest, not just the five which are selected for this work), “healthy people”, “observational study” and “experimental study” designs. Synonyms of these concepts were used to amplify the scope. The complete search strategy for each database is presented in Appendix 2.

2.4 Study selection process

Studies were selected independently by the reviewers A. A. and I. A. Exportation and storage of records from databases was done using Endnote 20. Processing of duplicates was done using “SR Accelerator-Deduplicator tool” and double-checked by “Endnote removing duplicate’s tool”. After removing duplicates, independent screening processes were performed manually through the “SR Accelerator-Screenatron tool”.

In the first stage, the titles of studies found through the search strategy were screened against the eligibility criteria and a shared keyword list created by the authors based on the review's purpose. In a second stage, the abstracts were reviewed and screened based on eligibility criteria. The last stage consisted in reading the full-text documents and comparing them directly with our eligibility criteria. At each stage, the agreement between reviewers was assessed using “SR Accelerator-Disputatron tool”, providing a kappa coefficient and percentage of agreement. Disagreements between reviewers were resolved by consensus and if not, were resolved by the third reviewer M. M-V. If no full text was available or data was missing, the corresponding author of the article was contacted. In case of failure to get them, we only proceeded with available data and addressed it in Discussion section. This process was the same for the records found by manual search.

2.5 Data extraction process

Data extraction was carried out jointly by the same two reviewers, using a standardized form on Microsoft Excel (Office 365). The following data were extracted:

- **Characteristics of included studies and socio-demographics data:** first author; year of publication; study design; inclusion and exclusion criteria; neurological condition of interest; number, age and gender of cases and HCs.
- **Clinical characteristics of cases**: time since diagnosis; most affected side (if applicable); scale or tool measuring the motor function/disability associated to the motor deficits.
- **Assessment of MI ability:** type of MI measure (behavioural, neurophysiological or both), MI domain assessment (implicit or explicit), MI behavioural method, behavioural assessment task/tool and outcome measures (see below for more details).
- **Conclusion of statistical analyses and summary of results**.

2.6 Outcome measures of interest

In this review that focuses on behavioural MI ability measures, we considered the following outcomes based on the two domains of the MI process.

2.6.1 Implicit domain of motor imagery

This domain of MI was commonly assessed through a body mental rotation task and accounted for the dimension of “transformation” ability. Even if their validity and reliability were not explicitly mentioned in the existing literature (Suica et al., 2022), two tasks widely used to assess body centred mental transformation ability are the Hand Laterality Judgment Task (HLJT), and its homologue for lower limbs, the Foot Laterality Judgment Task (FLJT). These tasks require participants to judge the laterality of presented hand or foot images. For HLJT, pictures of the back and the palm view of the hand are presented in different rotated orientations. Participants are asked to respond as quickly and accurately as possible when they think a left or a right hand appeared. The task accuracy (% of correct answers) or error rate (% of incorrect answers) and the reaction time (RT) for each stimulus (usually only for the correct responses, in milliseconds or seconds) represent the outcomes measured. This description is the same for FLJT except for the stimuli (Boonstra et al., 2012). Note that the effective use of MI in these tasks is typically identified by a specific behavioural phenomenon known as the ‘biomechanical constraints’ effect. It is a phenomenon in which we observe that RTs for pictures rotated laterally (e.g. fingers pointing away from the body for hand stimuli) are longer than those rotated medially. This phenomenon is regarded as a behavioural feature of performing MI of body parts because, the RT increase for lateral rotation is thought to stem from the fact that it is more difficult to physically rotate hands/feet laterally than to rotate them medially (Mibu et al., 2020).

2.6.2 Explicit domain of motor imagery

This domain of MI was commonly assessed through questionnaires and mental chronometry. There are plenty of questionnaires used in the literature to assess MI ability, concretely these measures assess the ability to generate MI and its associated vividness.

The most used are the Movement Imagery Questionnaire (MIQ) with its different versions (MIQ-3, MIQ-R, MIQ-RS), the Kinesthetic and Visual Imagery Questionnaire (KVIQ) with its different versions (KVIQ-20, KVIQ-10, KVIQ-34) and the Vividness of Movement Imagery Questionnaire (VMIQ) with its different versions (e.g VMIQ-2). For a review, see the work of Suica et al. (2022). There are other questionnaires related to other modalities of mental imagery and not specific to MI (e.g., visual, auditory) which were not considered for this review (e.g., the Vividness of Visual Imagery Questionnaire, VVIQ). Regarding the outcome measures of the questionnaires, studies usually report the overall score or the subscale score (typically visual/kinesthetic modalities for MI are used). Some studies report the mean score at the item level. Note that all these questionnaires typically use Likert-type scale ranging from 1-5 or 1-7 to assess MI generation.

Mental chronometry provides information about the temporal coupling between real and imagined movements (i.e., maintenance or temporal accuracy). There is no predefined task to assess it, but the main concept/procedure is that the time required to complete the real and the imagined task are recorded and then compared in order to see if there is isochrony or good temporal congruence. In terms of outcome measures, there is high heterogeneity, considering the raw difference in seconds, the relative difference in percentage, the ratio of imagery/execution, or the delta time, amongst other (Collet et al., 2011; Malouin et al., 2008b). Each measure has its own mathematical properties.

2.7 Risk of Bias assessment

The two reviewers (AA and AI) carried out the Risk of Bias (RoB) assessment independently using the **Joanna Briggs Institute's (JBI) Critical Appraisal checklist for Case-control studies** (Moola S, 2020) (Appendix 3). It is a valid checklist with 10 items (Barker et al., 2022) and is a part of JBI Critical Appraisal tools for assessing observational studies, including cross-sectional studies. For the studies with other design than case-control which were included (e.g. cross-sectional studies and randomized controlled trials-RCTs) we still used the mentioned checklist. The reason is the quality of data extracted from these studies is better assessed by this checklist in the way that: for RCTs, it did not matter if randomization, blinding procedure or correct intervention process were made because only baseline data were extracted; regarding cross-sectional studies, this checklist for case-control studies includes the items of the corresponding checklist (JBI Critical Appraisal checklist for Cross-sectional studies).

Each record was then screened by the checklist items and the reviewers selected one answer for each item from “yes”, “unclear”, “no”, or “not applicable”, where it was appropriate. RoB was decided based on the following criteria: Low RoB =

studies with 7 to 9 "yes"; moderate RoB = studies with 4 to 6 "yes"; high RoB = studies with 0 to 3 "yes". Considering that 1 “yes” = 1 point and a maximum of 1 point per item, the total RoB score was out of 9 rather than 10 points. The reason is that, item 9 (“Was the exposure period of interest long enough to be meaningful?”) was “not applicable” for all studies included. Indeed, as “measurement of exposure” is considered in this work to be the act of measurement of MI ability, the point that the duration of exposure should be sufficient to show an association between exposure and outcome, is not relevant, and therefore it was not considered. As recommended by the JBI reviewers' manual, all decisions regarding the scoring system and cut-off points were approved by all reviewers before the start of the critical appraisal process (Munn et al., 2019; Ravat et al., 2018). Agreement between the two reviewers was calculated as kappa coefficient for the categorical scores (low, moderate, high RoB) and the intraclass correlation coefficient for the numerical scores (0-9 points).

2.8 Qualitative synthesis of evidence

The qualitative synthesis of evidence was based on an adaptation method proposed by La Touche (La Touche et al., 2018) which included additional modification from a recent work (Fierro-Marrero et al., 2024). The levels of evidence were categorized as follows:

- “No evidence”: Absence of observational studies, including cross-sectional or longitudinal studies.
- “Contradictory evidence”: Inconsistent findings among multiple studies (cross-sectional and longitudinal observational studies).
- “Limited evidence”: One low-quality case–control study and/or cohort study and/or at least two cross-sectional studies of low quality ; it has also been considered the presence of one or two low-quality and/or one or two moderate-quality cross-sectional studies. **Here, we made a modification** including one or two moderate quality case-control studies.
- “Moderate evidence”: Consistent findings from multiple low-quality case–control studies and/or cohort studies and/or cross-sectional studies or one high-quality case–control study and/or cohort study. They also considered the presence of one or two high-quality cross-sectional

studies. For this category, **our modification included** two high-quality case–control studies.

- "Strong evidence": Consistent findings among multiple high-quality case–control studies and/or cohort studies and/or cross-sectional studies (at least three of these studies).

2.9 Quantitative synthesis: statistical analysis

Quantitative analysis was carried out via random effects meta-analysis using the inverse variance method (Hedges & Olkin, 1985). Standardized Mean Differences (SMD) between cases and controls were computed for each study. Given the limited sample sizes in each individual study, the SMD was computed as the bias corrected Hedges' *g* and were interpreted as small, medium, or large if $g < 0.3$, 0.3-0.8 and > 0.8, respectively (Egger et al., 1997). For the studies that did not report the data as mean and SD, these were calculated from the median and inter-quartile range as previously recommended (Wan et al., 2014). Heterogeneity variance was estimated as tau-squared (τ^2) (Veroniki et al., 2016) by the Restricted Maximum Likelihood procedure (Viechtbauer, 2005). 95% Confidence Intervals (95%CI) around the pooled effect were calculated with the Knapp-Hartung adjustment (Knapp & Hartung, 2003). Between-study heterogeneity was also estimated as the I^2 statistic (Higgins & Thompson, 2002) and interpreted as 0-25% = low, 25-75% = moderate, 75-100% = substantial heterogeneity (Higgins & Thompson, 2002). Forest plots were generated to summarize each meta-analysis findings. Presence of publication bias was assessed by Egger's test (Egger et al., 1997).

We ran separate meta-analyses for each neurological condition and MI ability domain. For imagery vividness/generation, separate analyses for kinesthetic, visual and global imagery scores were performed as they represent different modalities of imagery ability. Furthermore, we performed separate meta-analyses for the HLJT, in terms of accuracy (%) and RT (seconds).

For the HLJT, if a study reported errors or error rates instead of accuracy, means were transformed into negative values to maintain the direction of the effect across studies, as per recommended by the Cochrane Handbook (https://training.cochrane.org/handbook/current/chapter-06). Same transformation were made if the Likert-type scale was inverted (i.e. "1 = very clear image or intensity to 5 = no image/sensations at all" instead of "1 = no image/sensation at all to 5 = very clear image or intensity"). If a study reported imagery data divided into unaffected and affected hemi-bodies, we always pooled the data from the affected side. A p-value < 0.05 was considered as a statistically significant difference between the groups.

All these procedures were conducted in R software version 4.3.2 (R Core Team 2024) using the "meta" package version 7.0-0 (Balduzzi et al., 2019).

3 RESULTS

3.1 Selection process

Of the total of 3,050 records that were identified, 199 met the general inclusion criteria, and finally 59 were included for the present work after selecting based on condition and imagery assessment. Figure 2 provides an overview of all databases and identified references, and Figure 3 specifically shows the pathologies included in this work. The agreement at the various stages is shown in Table 2. All conflicts between reviewers were discussed and we reached agreement on decisions..

Table 2: Agreement between reviewers in the screening process and the Risk Of Bias assessment process.

Screening step	Kappa Coefficient	Percentage of agreement
Titles	0.64	83.45%
Abstracts	0.77	88.71%
Full-texts	0.54	79.93%
Risk of Bias assessment	**Kappa Coefficient[1]**	**ICC[1]**
Overall	0.863 [0.735 ; 0.992]	0.893 [0.827; 0.935]
Stroke	0.847 [0.646 ; 1]	0.839 [0.677; 0.923]
Parkinson's disease	0.876 [0.642 ; 1]	0.787[0.46 ; 0.926]
Multiple sclerosis	ND	ND
Traumatic Brain Injury	NA	NA
Cerebral Palsy	ND	ND

[1] **KC and ICC** = estimate [lower; upper 95% confidence interval]; **ND**: No Discrepancies; **NA**: Not Applicable

3.2 Overall study characteristics

Of the 59 articles selected, 27 dealt with stroke, 14 with PD and 11 with MS. Those dealing with CP and TBI were 6 and 1 respectively. Most of the articles (n = 52) were case-control studies, with 4 cross-sectional studies and 3 randomized controlled trial studies. Studies had only low (n = 29) and moderate (n = 30) RoB. The main data extracted are presented below in Tables 3-7 and the RoB assessment checklists for each condition in the appendix.

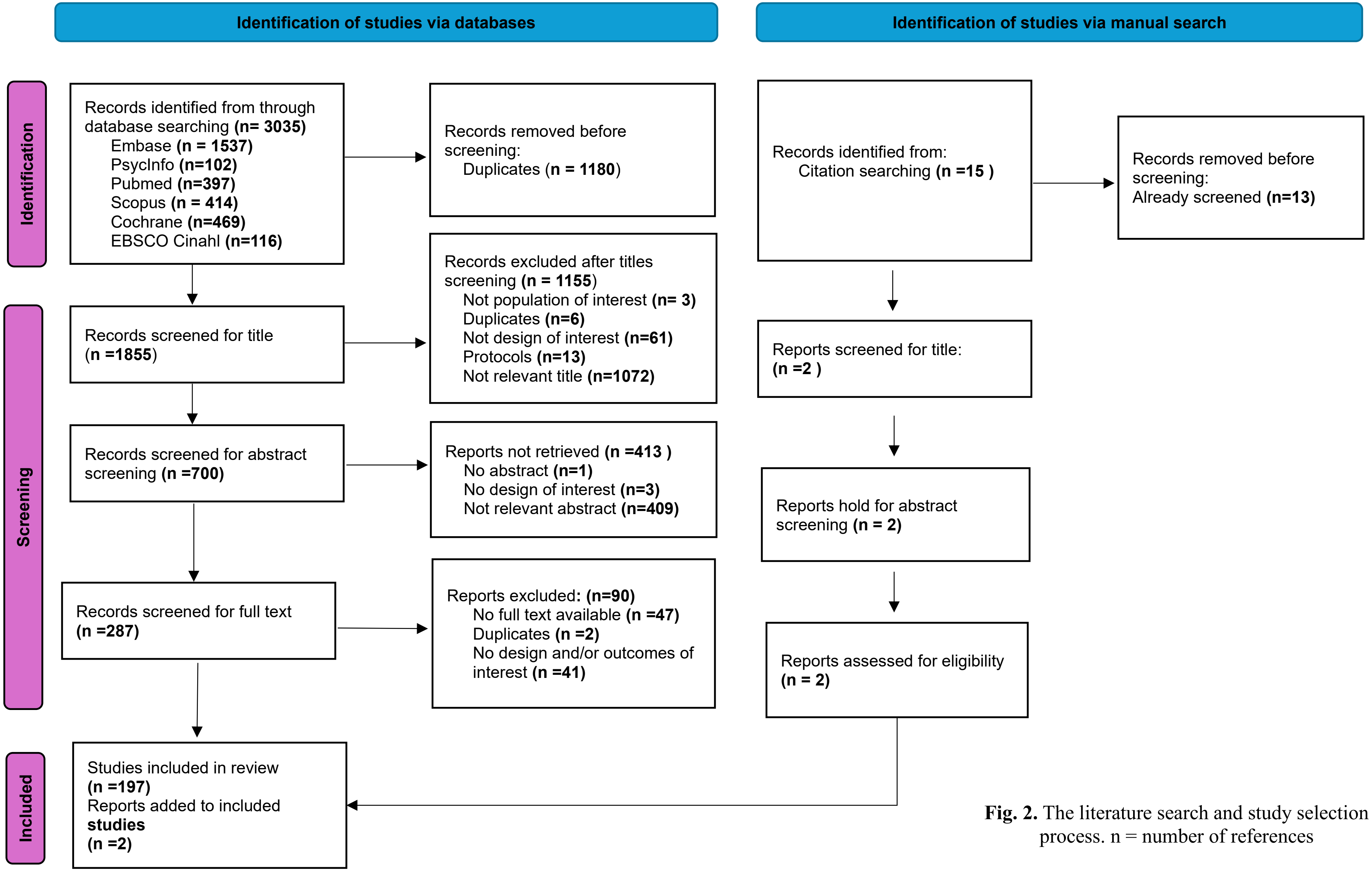


Fig. 2. The literature search and study selection process. n = number of references

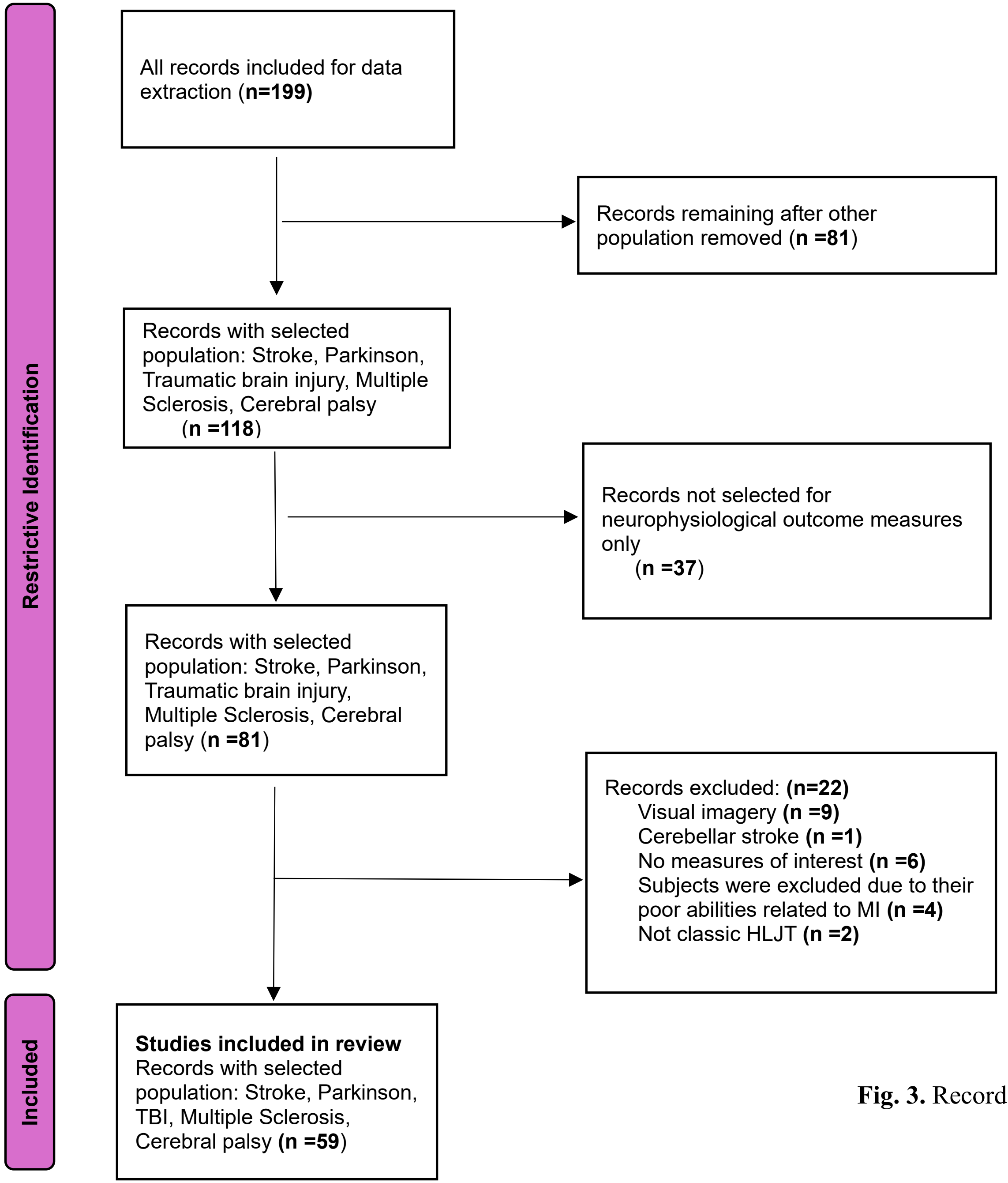


Fig. 3. Records finally selected for this work. n = number of references

3.3 Stroke

3.3.1 Studies and participants characteristics

Twenty-seven studies were included (with n = 717 cases and n = 506 controls). Twenty-two (81.48%) had a case-control design, 3 (11.11%) had a cross-sectional design and 2 (7.41%) an RCT design. The mean ± SD score of the JBI was 6.04 ± 0.98 points, with 10 and 17 studies rated as low and moderate RoB, respectively. All cross-sectional studies had a low RoB and the 2 RCTs had a moderate RoB. Among case-control studies, 7 (25.92%) had a low RoB and 15 (55.55%) had a moderate RoB (Appendix 4).

Regarding participant's characteristics, the weigthed mean ± SD age was 59.26 ± 5.79 and 58.42 ± 6.32 years for cases and controls respectively, with a range of 44 to 70 years. There was a slight male predominance in the case group (51.46%) against 44.86% in the control group. Inclusion and exclusion criteria were heterogenous but encompassed for inclusion: Confirmed diagnosis of a stroke through brain neuroimaging exam, subacute to chronic stage of stroke, no evidence of significant arrhythmia or myocardial ischemia, low to severe motor disability, right-handed, complying with the requirements of the MI assessment task. For exclusion criteria: previous history of stroke, pre-existing cognitive impairments or patients who were medically unstable, cardiopulmonary hospitalization; significant ataxia or neglect, severe hypertonia, depression, botulinum toxin injection, progressive neurologic disorder, epileptic seizures, dementia, withdrawing, blindness and severe congenital or acquired visual deficits, psychiatric conditions, balance trouble, bilateral cortical lesions, cerebellar stroke, musculoskeletal surgery less than six months previously, evidence of substance abuse known to affect brain excitability, patients with severe pain.

Twenty-two studies explored explicit MI with more (81.81%) using a questionnaire assessment method than mental chronometry (50%) and both assessment method (31.31%), whereas 10 studies assessed implicit MI (8 used the HLJT, 1 used a mixed FLJT-HLJT task and 1 the first component of Chaotic Motor Imagery Assessment).

The following questionnaires were used : KVIQ-20 (8 studies), KVIQ-10 (2 studies), MIQ-RS (4 studies), a combination of MIQ-RS and MIQ-R (2 studies), MIQ-3 (1 study), a “modified KVIQ-20” with only one hand’s gesture by each component (2 items and maximal score of 10), a “self-reported 0-5 scale” on kinesthetic imagery and a “modified MIQ” from which items irrelevant to hemiparetic patients were discarded with 8 items remains. Mental chronometry paradigms were made with executed and imagined: Nine-Hole Peg Test, Time Up and Go test, Expanded Time Up and Go test, Classic Walking Task, Walk Trajectory Task, Hand Movement Task, Stepping Task and a modified Box and Block Test with 15 blocks. The Hand Movement Task was used in 2 studies and the modified Box and Block Test in 3 studies. The remaining were used in only 1 study each.

3.3.2 Outcomes measured

For **implicit** MI, outcome measures were homogeneous as only RT and accuracy/error rate from laterality judgment tasks were measured.

Concerning **explicit** MI assessed by questionnaires, outcome measures were less homogeneous as even though they were the kinesthetic imagery, the visual imagery and/or overall imagery vividness/generation ability for outcomes, data were provided by different scales (more details below in Table 3).

A heterogeneity issue concerned the mental chronometry tests, as not only there is a diversity of temporal congruence test paradigms, but also the measure of temporal congruence was not the same for all of them. Outcomes were too diverse, encompassing mental chronometry ratios, correlation coefficient and many others (see details below in Table 3), but with the common aim of providing an indication of temporal congruence.

Table 3: Characteristics of included studies for stroke's condition

Authors and design	RoB	JBI Score	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
(Amesz et al., 2016) Cross-sectionnal	LOW	7	Implicit	HLJT	Reaction time (second)	<	Impaired Mental Rotation ability
					Accuracy (%)	<	
(Boyne et al., 2021) Cross-sectionnal	LOW	7	Explicit	KVIQ-10	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
(Braun et al., 2017) Case-control study	MODERATE	6	Implicit	Hand and Foot Laterality Judgment Task	Accuracy (%)	<	Impaired Mental Rotation ability
			Explicit	Nine-Hole Peg Test and imagined Nine-Hole Peg Test	Mental chronometry score	<	Impaired Mental Chronometry ability
(Daprati et al., 2010) Case-control study	MODERATE	5	Implicit	HLJT	Reaction time (millisecond)	<	LBD patients are more slower than HC and RBD patients
					Accuracy (%)	<	RBD patients are less accurate than HC and LBD patients.
(De Bartolo et al., 2020) Case-control study	MODERATE	6	Explicit	KVIQ-20	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				Real and imagined Walking Task	Incongruity Performance Index (%)	=	Preserved Mental Chronometry ability
(de Vries et al., 2013) Case-control study	MODERATE	5	Explicit	MIQ-RS	Visual Imagery Score	<	Impaired Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	<	
			Implicit	HLJT	Reaction time (millisecond)	<	Preserved mental rotation ability but with slowness of motor planning
					Accuracy (%)	=	
(Demanboro et al., 2018) Case-control study	LOW	7	Explicit	KVIQ-20	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				KVIQ-10	Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	=	
(Dickstein et al., 2005) Case-control study	MODERATE	4	Explicit	Modified MIQ	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
(Geiger et al., 2017) Case-control study	LOW	7	Explicit	MIQ-R and MIQ-RS	Global Score in %	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				TUG and iTUG	Temporal congruence	<	Impaired Mental Chronometry ability
(Geiger et al., 2018) Case-control study	LOW	7	Explicit	MIQ-R and MIQ-RS	Total Score in %	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				ETUG and iETUG	Temporal congruence	=	Preserved Mental Chronometry ability

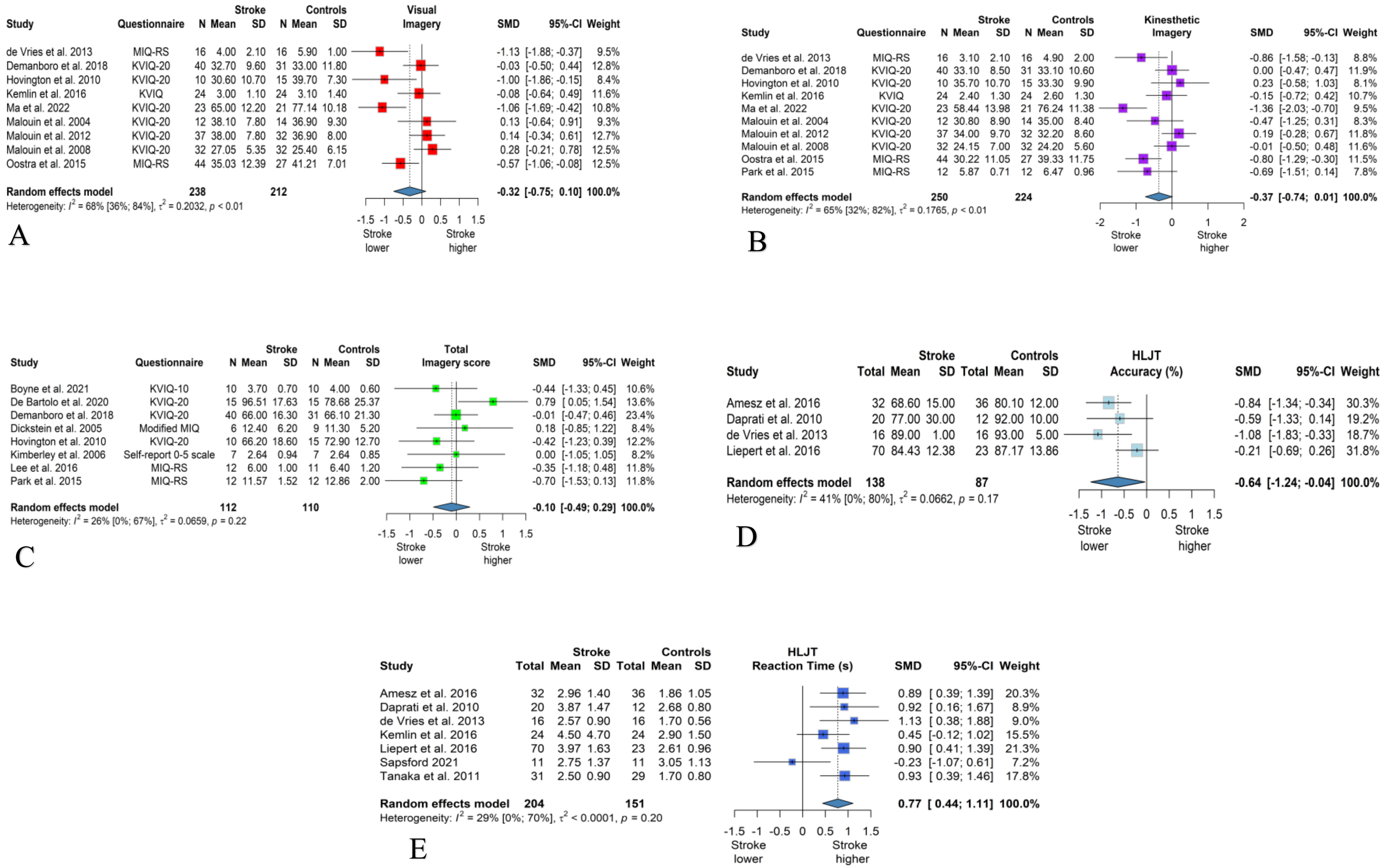
Table 3 (continued)

Authors and design	RoB	JBI Score	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
(Hovington & Brouwer, 2010) Case-control study	MODERATE	5	Explicit	KVIQ-20	Kinesthetic Imagery Score	=	Preserved Vividness of Kinesthetic motor imagery but Impaired Vividness of Visual motor imagery
					Visual Imagery Score	<	
					Total Score	=	
(Ietswaart et al., 2011) RCT	MODERATE	6	Explicit	Imagined and Executed finger thumb opposition	Motor imagery ability	=	Preserved Mental Chronometry ability
(Kemlin et al., 2016) Case-control study	MODERATE	5	Explicit	Modified KVIQ-20	Kinesthetic Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Visual Imagery Score	=	
				Real and Imagined Hand Movement	Temporal congruence (correlation coefficient)	<	Preserved Mental Chronometry ability in left-sided patients Impaired Mental Chronometry ability in right-sided patients
			Implicit	HLJT	Reaction time (second)	<	Impaired Mental Rotation ability
				HLJT	Accuracy (%)	<	
(Kimberley et al., 2006) Case-control study	MODERATE	6	Explicit	Self-reported 0-5 scale	Total Score	=	Preserved Vividness of Kinesthetic motor imagery
(Kolbaşı et al., 2020) Case-control study	LOW	7	Explicit	MIQ-3	Internal Visual Imagery Score	=	Preserved Vividness of Visual motor imagery
					External Visual Imagery Score	=	
					Kinesthetic Imagery Score	>	Preserved Vividness of Kinesthetic motor imagery
				Modified BBT and iBBT	Mental chronometry ratio	<	Impaired Mental Chronometry ability
			Implicit	CMIA-I	Total test time (second)	<	Impaired Mental Rotation ability
					Total accuracy (%)	<	
(Lee et al., 2016) Case-control study	MODERATE	5	Explicit	MIQ-RS	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
(Liepert et al., 2016) Case-control study	MODERATE	6	Explicit	Modified BBT and iBBT	Mental chronometry ratio	<	Impaired Mental Chronometry ability
			Implicit	HLJT	Reaction time (second)	<	Preserved mental rotation ability but with slowness of motor planning
					Accuracy (%)	=	

Table 3 (continued)

Authors and design	RoB	JBI Score	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
(Liepert et al., 2012) Case-control study	MODERATE	5	Explicit	Modified BBT and iBBT	Mental chronometry ratio	<	Impaired Mental Chronometry ability in patients with sensorimotor deficit but Preserved in patients with pure motor deficit
(Ma et al., 2022) Cross-sectionnal study	LOW	7	Explicit	KVIQ-20	Visual Imagery Score	<	Impaired Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	<	
(Malouin et al., 2004) Case-control study	MODERATE	5	Explicit	KVIQ-20	Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	=	
(Malouin et al., 2012) Case-control study	MODERATE	6	Explicit	KVIQ-20	Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	=	
				Real and Imagined Stepping task	Temporal congruence ratio	<	Impaired Mental Chronometry ability
(Malouin et al., 2008a) Case-control study	LOW	7	Explicit	KVIQ-20	Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	=	
(Oostra et al., 2015) RCT	MODERATE	6	Explicit	MIQ-RS	Visual Imagery Score	<	Impaired Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	<	
				Real and Imagined Walking trajectory test	Ratio “Imagined Walking time/ Actual Walking time”	=	Preserved Mental Chronometry ability
(Park et al., 2015) Case-control study	MODERATE	5	Explicit	MIQ-RS	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
(Sapsford, 2021) Case-control study	LOW	8	Implicit	HLJT	Reaction time (millisecond)	=	Preserved Mental Rotation ability
					Number of error	=	
(Tanaka et al., 2011) Case-control study	MODERATE	6	Implicit	HLJT	Reaction time (second)	<	Impaired Mental Rotation ability
(Yan et al., 2012) Case-control study	LOW	7	Implicit	HLJT	Reaction time (millisecond)	<	Impaired Mental Rotation ability
					Accuracy (%)	<	

RoB: Risk of Bias; **JBI**: Joanna Briggs Institute's checklist; **MI**: motor imagery; **KVIQ-10**: Kinesthetic and Visual Imagery Questionnaire-10 items; **KVIQ-20**: Kinesthetic and Visual Imagery Questionnaire-20 items; **HLJT**: Hand Laterality Judgement Task; **MIQ**: Movement Imagery Questionnaire; **MIQ-R**: MIQ-revised version; **MIQ-RS**: MIQ-second revised version; **MIQ-3**: MIQ-third revised version; **BBT**: Box and Bloc Test; **iBBT**: imagined BBT; **CMIA-I**: first component of Chaotic Motor Imagery Assessment; **TUG**: Time up and Go Test; **iTUG**: imagined TUG; **ETUG**: Expanded Time up and Go Test; **iETUG**: imagined ETUG; **LBD**: Left brain damage; **RBD**: Right brain damage; **HCs**: Healthy controls; **<**: cases are worse than HCs; **=**: cases are similar to HCs; **>**: cases perform better than HCs



		Stroke			Controls					
Study	**Questionnaire**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**SMD**	**95%-CI**	**Weight**
de Vries et al. 2013	MIQ-RS	16	4.00	2.10	16	5.90	1.00	-1.13	[-1.88; -0.37]	9.5%
Demanboro et al. 2018	KVIQ-20	40	32.70	9.60	31	33.00	11.80	-0.03	[-0.50; 0.44]	12.8%
Hovington et al. 2010	KVIQ-20	10	30.60	10.70	15	39.70	7.30	-1.00	[-1.86; -0.15]	8.4%
Kemlin et al. 2016	KVIQ	24	3.00	1.10	24	3.10	1.40	-0.08	[-0.64; 0.49]	11.6%
Ma et al. 2022	KVIQ-20	23	65.00	12.20	21	77.14	10.18	-1.06	[-1.69; -0.42]	10.8%
Malouin et al. 2004	KVIQ-20	12	38.10	7.80	14	36.90	9.30	0.13	[-0.64; 0.91]	9.3%
Malouin et al. 2012	KVIQ-20	37	38.00	7.80	32	36.90	8.00	0.14	[-0.34; 0.61]	12.7%
Malouin et al. 2008	KVIQ-20	32	27.05	5.35	32	25.40	6.15	0.28	[-0.21; 0.78]	12.5%
Oostra et al. 2015	MIQ-RS	44	35.03	12.39	27	41.21	7.01	-0.57	[-1.06; -0.08]	12.5%
Random effects model		**238**			**212**			**-0.32**	**[-0.75; 0.10]**	**100.0%**

Heterogeneity: $I^2 = 68\%$ [36%; 84%], $\tau^2 = 0.2032$, $p < 0.01$

		Stroke			Controls					
Study	**Questionnaire**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**SMD**	**95%-CI**	**Weight**
de Vries et al. 2013	MIQ-RS	16	3.10	2.10	16	4.90	2.00	-0.86	[-1.58; -0.13]	8.8%
Demanboro et al. 2018	KVIQ-20	40	33.10	8.50	31	33.10	10.60	0.00	[-0.47; 0.47]	11.9%
Hovington et al. 2010	KVIQ-20	10	35.70	10.70	15	33.30	9.90	0.23	[-0.58; 1.03]	8.1%
Kemlin et al. 2016	KVIQ	24	2.40	1.30	24	2.60	1.30	-0.15	[-0.72; 0.42]	10.7%
Ma et al. 2022	KVIQ-20	23	58.44	13.98	21	76.24	11.38	-1.36	[-2.03; -0.70]	9.5%
Malouin et al. 2004	KVIQ-20	12	30.80	8.90	14	35.00	8.40	-0.47	[-1.25; 0.31]	8.3%
Malouin et al. 2012	KVIQ-20	37	34.00	9.70	32	32.20	8.60	0.19	[-0.28; 0.67]	11.8%
Malouin et al. 2008	KVIQ-20	32	24.15	7.00	32	24.20	5.60	-0.01	[-0.50; 0.48]	11.6%
Oostra et al. 2015	MIQ-RS	44	30.22	11.05	27	39.33	11.75	-0.80	[-1.29; -0.30]	11.5%
Park et al. 2015	MIQ-RS	12	5.87	0.71	12	6.47	0.96	-0.69	[-1.51; 0.14]	7.8%
Random effects model		**250**			**224**			**-0.37**	**[-0.74; 0.01]**	**100.0%**

Heterogeneity: $I^2 = 65\%$ [32%; 82%], $\tau^2 = 0.1765$, $p < 0.01$

		Stroke			Controls					
Study	**Questionnaire**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**SMD**	**95%-CI**	**Weight**
Boyne et al. 2021	KVIQ-10	10	3.70	0.70	10	4.00	0.60	-0.44	[-1.33; 0.45]	10.6%
De Bartolo et al. 2020	KVIQ-20	15	96.51	17.63	15	78.68	25.37	0.79	[0.05; 1.54]	13.6%
Demanboro et al. 2018	KVIQ-20	40	66.00	16.30	31	66.10	21.30	-0.01	[-0.47; 0.46]	23.4%
Dickstein et al. 2005	Modified MIQ	6	12.40	6.20	9	11.30	5.20	0.18	[-0.85; 1.22]	8.4%
Hovington et al. 2010	KVIQ-20	10	66.20	18.60	15	72.90	12.70	-0.42	[-1.23; 0.39]	12.2%
Kimberley et al. 2006	Self-report 0-5 scale	7	2.64	0.94	7	2.64	0.85	0.00	[-1.05; 1.05]	8.2%
Lee et al. 2016	MIQ-RS	12	6.00	1.00	11	6.40	1.20	-0.35	[-1.18; 0.48]	11.8%
Park et al. 2015	MIQ-RS	12	11.57	1.52	12	12.86	2.00	-0.70	[-1.53; 0.13]	11.8%
Random effects model		**112**			**110**			**-0.10**	**[-0.49; 0.29]**	**100.0%**

Heterogeneity: $I^2 = 26\%$ [0%; 67%], $\tau^2 = 0.0659$, $p = 0.22$

	Stroke			Controls					
Study	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**SMD**	**95%-CI**	**Weight**
Amesz et al. 2016	32	68.60	15.00	36	80.10	12.00	-0.84	[-1.34; -0.34]	30.3%
Daprati et al. 2010	20	77.00	30.00	12	92.00	10.00	-0.59	[-1.33; 0.14]	19.2%
de Vries et al. 2013	16	89.00	1.00	16	93.00	5.00	-1.08	[-1.83; -0.33]	18.7%
Liepert et al. 2016	70	84.43	12.38	23	87.17	13.86	-0.21	[-0.69; 0.26]	31.8%
Random effects model	**138**			**87**			**-0.64**	**[-1.24; -0.04]**	**100.0%**

Heterogeneity: $I^2 = 41\%$ [0%; 80%], $\tau^2 = 0.0662$, $p = 0.17$

	Stroke			Controls					
Study	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**SMD**	**95%-CI**	**Weight**
Amesz et al. 2016	32	2.96	1.40	36	1.86	1.05	0.89	[0.39; 1.39]	20.3%
Daprati et al. 2010	20	3.87	1.47	12	2.68	0.80	0.92	[0.16; 1.67]	8.9%
de Vries et al. 2013	16	2.57	0.90	16	1.70	0.56	1.13	[0.38; 1.88]	9.0%
Kemlin et al. 2016	24	4.50	4.70	24	2.90	1.50	0.45	[-0.12; 1.02]	15.5%
Liepert et al. 2016	70	3.97	1.63	23	2.61	0.96	0.90	[0.41; 1.39]	21.3%
Sapsford 2021	11	2.75	1.37	11	3.05	1.13	-0.23	[-1.07; 0.61]	7.2%
Tanaka et al. 2011	31	2.50	0.90	29	1.70	0.80	0.93	[0.39; 1.46]	17.8%
Random effects model	**204**			**151**			**0.77**	**[0.44; 1.11]**	**100.0%**

Heterogeneity: $I^2 = 29\%$ [0%; 70%], $\tau^2 < 0.0001$, $p = 0.20$

Fig. 4. Forest plots from quantitative analysis in stroke for (**A**) visual imagery, (**B**) kinesthetic imagery, (**C**) total imagery, (**D**) accuracy and (**E**) reaction time

3.3.3 Quantitative synthesis

Explicit imagery

We decided to exclude the papers from Geiger et al. because they used MIQ-R for controls and MIQ-RS for cases, which we thought was not appropriate for running analyses. For the mental chronometry tasks, we omitted them for analyses as there were multiple outcome measures used and pooling them would not have been a good strategy as each measure has its own mathematical properties.

Regarding vividness of **visual imagery**, the meta-analysis included 9 studies and 450 participants (n = 238 cases; n = 212 controls). Heterogeneity was moderate ($I^2 = 68.3\%$ [36.5; 84.2%]; $\tau^2 = 0.2$ [0.04; 1.08], Q(8) = 25.27, p = 0.0014), without evidence of publication bias (t(7) = -1.83, p = 0.1105). There was no statistical evidence of diminished MI ability for the visual modality in people with stroke compared to HCs, although a small to moderate effect size was found (SMD = -0.324 [-0.752; 0.104], t = -1.75, p = 0.1191; Figure 4A).

Analyses for vividness of **kinesthetic imagery** included 10 studies and 474 participants (n=250 cases and n= 224 control). There was moderate heterogeneity in the results, with $I^2 = 65.4\%$ [32.1; 82.3%]; $\tau^2 = 0.17$ [0.03; 0.81]; Q(9) = 26, p = 0.0020. There was neither evidence of publication bias (t(8) = -1.24, p = 0.2506), nor about a diminished vividness of kinesthetic MI ability, but still with a small to moderate effect size (SMD = -0.366 [-0.741; 0.009]; t = -2.21, p = 0.0548; Figure 4B).

The meta-analysis on the vividness of **overall MI** included 8 studies with a total of 222 participants. Of these, 112 were in the case group and 110 were in the control group. Heterogeneity in the results was small ($I^2 = 26.5\%$ [0; 66.8%]; $\tau^2 = 0.06$ [0; 0.74], Q(7) = 9.52, p = 0.2174). The analyses did not support impaired MI ability (SMD = -0.099 [-0.493; 0.293]; t = -0.60, p = 0.5672; Figure 4C).

Implicit imagery

We pooled the data for the HLJT, and therefore excluded the papers from Braun et al. (2017); Kolbaşı et al. (2020) that used other measures (see Table 3).

Regarding the **accuracy in the HLJT**, the meta-analysis included 4 studies (n = 225 participants; n = 138 cases and n = 87 controls). Heterogeneity was moderate

(I^2 = 41.0% [0; 80.0%]; τ^2 = 0.06 [0; 1.82], Q(3) = 5.08, p = 0.1660), without evidence of publication bias (t(2) = -0.89, p = 0.4674). There was statistical evidence of impaired mental body transformation ability on the accuracy rate in people with stroke compared to HCs, with a moderate effect size (SMD = -0.638 [-1.240; -0.037], t = -3.38, p = 0.0431; Figure 4D).

The meta-analysis on the **RT in the HLJT** included 7 studies with a total of 355 participants. Of these, 204 were in the case group and 151 were in the control group. The analysis found small heterogeneity in the results, with an I^2 value of 29.3% [0; 69.6%]; τ^2 < 0.001 [0; 0.87]; Q(6) = 8.48, p = 0.2049. There was no evidence of publication bias (t(5) = -1.02, p = 0.3558). There was evidence of an impaired mental body transformation ability based on the RT, with a moderate effect size (SMD = 0.773 [0.438; 1.108]; t = 5.65, p = 0.0013; Figure 4E).

3.3.4 Qualitative synthesis of temporal congruence

For temporal congruence, **strong evidence** from **4 moderate RoB case-control studies** (Braun et al., 2017; Liepert et al., 2016; Liepert et al., 2012; Malouin et al., 2012) and **2 low RoB case-control studies** (Geiger et al., 2017; Kolbaşı et al., 2020) indicated patients with stroke perform worse than HCs. However, one of them (Liepert et al., 2012) showed this impaired ability to maintain MI only for patients with sensorimotor deficits, with patients that had pure motor deficits being similar to HCs. On the contrary, **moderate evidence** from **2 case-control studies** with **moderate** (De Bartolo et al., 2020) and **low** (Geiger et al., 2018) **RoB** and **2 moderate RoB RCTs** (Ietswaart et al., 2011; Oostra et al., 2015) supported that stroke patients perform similarly than HCs.

One **moderate RoB case-control** study (Kemlin et al., 2016) presented contradictory findings regarding the side affected (same temporal congruence than HCs in left-sided patients) and was not considered.

3.4 Parkinson’s disease

3.4.1 Studies and participants characteristics

Fourteen studies were included (with n = 368 cases and n = 276 controls). All studies had a case-control design.

The mean ± SD score of the JBI was 6.14 ± 0.86 points, with 4 (28.57%) and 10 (71.43%) studies rated as low and moderate RoB, respectively (Appendix 5).

Regarding participant’s characteristics, the weighted mean ± SD age was 65.39 ± 5.59 and 63.73 ± 6.95 years for cases and controls, respectively, and ranged from 50 to 74 years. Men were more represented in the case group with 63.32% against 53.99% in the control group. Eligibility criteria were for inclusion: diagnosis of Parkinson's disease; Hoehn & Yahr stages 1-3; stable dopaminergic therapy; normal or corrected-to-normal vision; people with Parkinson's disease who reported gait freezing or no gait freezing. For exclusion criteria, there were: major depression according to DSM IV criteria, dementia or other neurological diseases, vestibular disorders, musculoskeletal gait disorders and inability to stand and walk for 20 minutes; Cognitive impairment (Mini-Mental State Examination < 24) ; any neurological disorder other than PD, epileptic seizures or use of certain drugs; severe tremors; unpredictable motor fluctuations; treatment with deep brain stimulation.

Eleven studies explored explicit MI with more (72.72%) questionnaire-based assessment methods than mental chronometry (27.27%), while 6 explored implicit MI. The following questionnaires were used: KVIQ-20 (5 studies), a Visual Analogical Scale assessing vividness (VAS for vividness) used by 2 studies, the MIQ-R, MIQ-RS, and VMIQ each by 1 study. Mental chronometry paradigms were made with real and imagined: Walking task, Hand Rhythmed task and Hand Movement task used by 1 study each. Mental rotation tasks were HJLT for all studies (6) except one, which used Chaotic Motor Imagery Assessment.

3.4.2 Outcomes measured

For **implicit** MI, outcome measures were homogeneous as only RT and accuracy/error rate from laterality judgment tasks were measured.

Concerning **explicit** MI assessed by questionnaires, outcome measures were less homogeneous as even though they were the kinesthetic imagery, the visual imagery and/or overall imagery vidvidness/generation which were reported, data were provided by different scales (more details in Table 4).

Table 4: Characteristics of included studies for Parkinson's disease condition

Authors and design	RoB	JBI Score	MI Domain	Behavioural assessment task/tool	Outcomes measure	Performance direction	Summary (compared to HCs)
(Avanzino et al., 2013) Case-control study	MODERATE	5	Explicit	Real and Imagined hand rythmed task	Temporal error	<	Impaired Mental Chronometry ability
					Interval reproduction accuracy index	<	
(Bek et al., 2019) Case-control study	LOW	8	Explicit	KVIQ-20	Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	=	
(Bek et al., 2022) Case-control study	MODERATE	6	Explicit	KVIQ-20	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
			Implicit	HLJT	Reaction time (millisecond)	=	Preserved Mental Rotation ability
					Accuracy (%)	=	
(Cohen et al., 2011) Case-control study	LOW	7	Explicit	Imagined and real walking task modulating width and distance	Time difference between real and imagined walking	<	Impaired Mental Chronometry ability in FoG patients
(Conson et al., 2014) Case-control study	MODERATE	6	Implicit	HLJT	Reaction time (millisecond)	=	Preserved Mental Rotation ability
					Accuracy (%)	=	
(Ferreira-Sánchez et al., 2023) Case-control study	LOW	7	Explicit	MIQ-RS	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				KVIQ-34	Total Score	=	
(Esculier et al., 2014) Case-control study	MODERATE	6	Explicit	VAS for Vividness	VAS Score for Imagery	<	Impaired Vividness of motor imagery

Table 4 (continued)

Authors and design	RoB	JBI Score	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
(Helmich et al., 2012) Case-control study	MODERATE	6	Implicit	HLJT	Reaction time (millisecond)	=	Preserved Mental Rotation ability
				HLJT	Error rate	=	
(Heremans et al., 2011) Case-control study	MODERATE	6	Explicit	MIQ-R	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				KVIQ-20	Total Score	=	
				CMIA-I	Reaction time (millisecond)	=	Preserved Mental Rotation ability
				CMIA-I	Accuracy (%)	=	
(Heremans, Nieuwboer, et al., 2012) Case-control study	MODERATE	5	Explicit	VAS for Vividness	VAS Score for Imagery	=	Preserved Vividness of motor imagery
(Huang et al., 2021) Case-control study	MODERATE	5	Explicit	VMIQ	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
(Peterson et al.) Case-control study	MODERATE	6	Explicit	KVIQ-20	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
(Scarpina et al., 2019) Case-control study	MODERATE	6	Implicit	HLJT	Reaction time (millisecond)	=	Preserved Mental Rotation ability
				HLJT	Accuracy (%)	=	
			Explicit	Real and Imagined Hand Movement	Index of relation between real and imagined movements	= <	Contradictory findings between left and right hand
(van Nuenen et al., 2012) Case-control study	LOW	7	Implicit	HLJT	Reaction time (millisecond)	=	Preserved Mental Rotation ability
				HLJT	Error rate (%)	=	

RoB: Risk of Bias; **JBI**: Joanna Briggs Institute's checklist; **MI**: motor imagery; **KVIQ-20**: Kinesthetic and Visual Imagery Questionnaire-20 items; **KVIQ-34**: Kinesthetic and Visual Imagery Questionnaire-34 items; **HLJT**: Hand Laterality Judgement Task; **MIQ-R**: Movement Imagery Questionnaire-revised version; **MIQ-RS**: Movement Imagery Questionnaire-second revised version; **CMIA-I**: first component of Chaotic Motor Imagery Assessment; **VAS**: Visual analogue scale; **VMIQ**: Vividness of Movement Imagery Questionnaire; **FoG**: Freezing of gait; **HCs**: Healthy controls; <: cases are worse than HCs; =: cases are similar to HCs

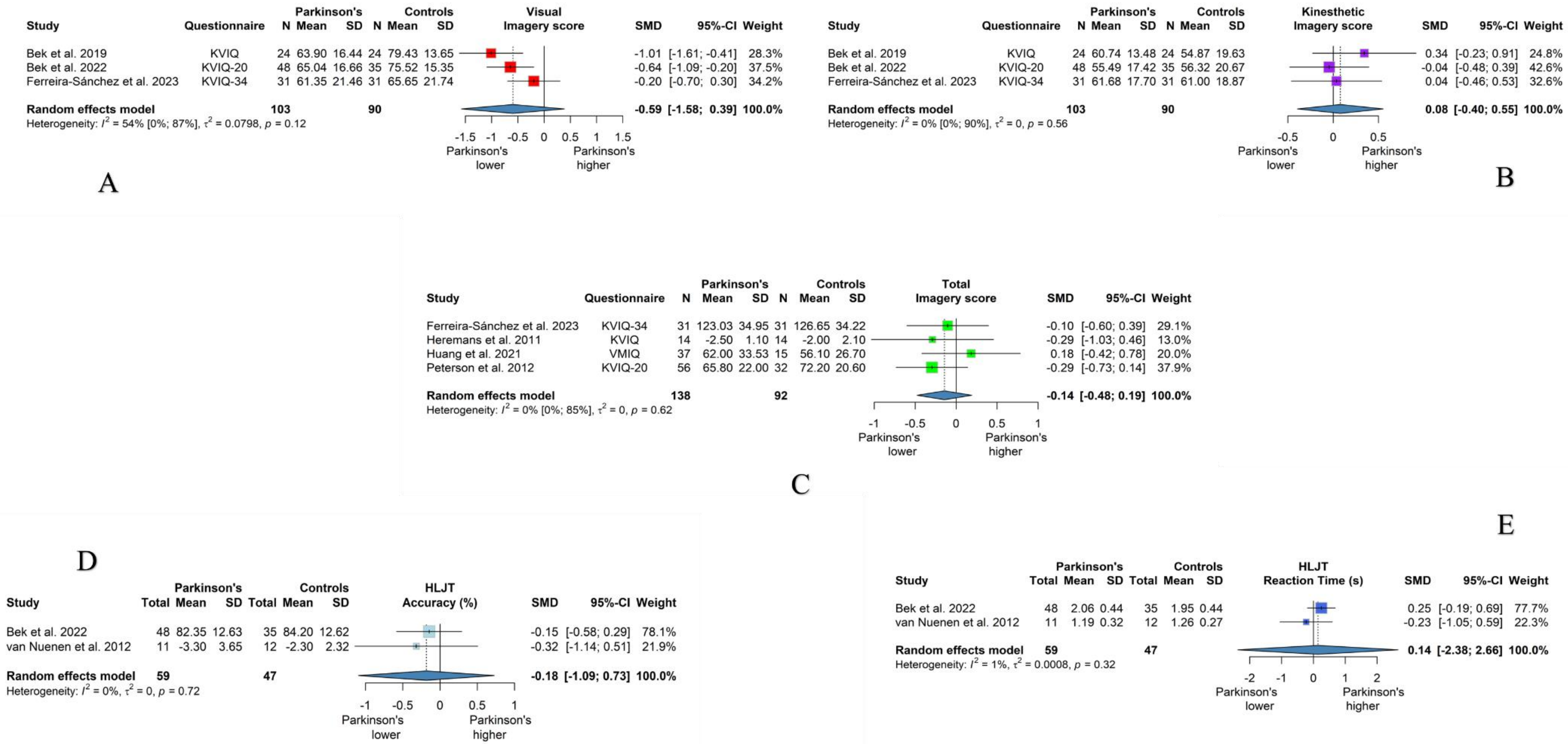


Fig. 5. Forest plots from quantitative analysis in Parkinson’s disease for (**A**) visual imagery, (**B**) kinesthetic imagery, (**C**) total imagery, (**D**) accuracy and (**E**) reaction time

Again, heterogeneity concerned mental chronometry outcomes. There were 3 studies which used 3 different tasks as said above, but also the outcomes reported were different (details in Table 4).

3.4.3 Quantitative synthesis

Explicit imagery

We excluded the papers from Esculier et al. (2014) and Heremans, Nieuwboer, et al. (2012) because they did not provide exploitable data for visual imagery. Then, they were not considered for running analyses. Obviously, studies which measured mental chronometry, were also omitted for analyses as data could not be pooled together. Note that for Ferreira-Sánchez et al. (2023) and Heremans et al. (2011), we only use the KVIQ data in order to avoid duplicating the studies.

Regarding vividness of **visual imagery**, the meta-analysis included 3 studies and 193 participants (n = 103 cases; n = 90 controls). Heterogeneity was moderate ($I^2 = 53.5\%$ [0; 86.7%]; $\tau^2 = 0.07$ [0; 6.49], Q(2) = 4.30, p = 0.1163), without evidence of publication bias (t(1) = -0.55, p = 0.6776). There was no statistical evidence of diminished MI ability for the visual modality in people with PD compared to HCs, although a moderate effect size was found (SMD = -0.594 [-1.576; 0.386], t = -2.61, p = 0.1210; Figure 5A).

Analyses for vividness of **kinesthetic imagery** included 3 studies and 193 participants (n = 103 cases and n = 90 control). There was small heterogeneity in the results, with an $I^2 = 0\%$ [0; 89.6%]; $\tau^2 = 0$ [0; 1.57]; Q(2) = 1.15, p = 0.5614. There was neither evidence of publication bias (t(1) = 3.25, p = 0.1898), nor about a diminished vividness of kinesthetic MI with a negligible effect size toward worse performance for cases SMD = -0.078 [-0.395; 0.552]; t = 0.71, p = 0.05497; Figure 5B).

The meta-analysis for **overall MI ability** included 4 studies and 230 participants (n = 138 cases; n = 92 controls). Results presented no heterogeneity ($I^2 = 0\%$ [0; 84.7%]; $\tau^2 = 0$ [0; 0.607], Q(3) = 1.77, p = 0.6219), without evidence of publication bias (t(2) = 0.44, p = 0.7054). Evidence from analyses supported a preserved overall vividness of MI but with a small trend toward impaired MI ability regarding effect size (SMD = - 0.142 [- 0.478; 0.192], t = -1.36, p = 0.2676; Figure 5C).

Implicit imagery

Several papers were excluded from analyses. Heremans et al. (2011) because they used other measures than the HLJT. Helmich et al. (2012) because they included hand and foot as stimuli and did not report exploitable data results only for hands. Scarpina et al. (2019) did not provide the data in a format we could pool. After this, only studies of Bek et al. (2022) and van Nuenen et al. (2012) remained, so we ran the analysis with these two.

There were 106 participants (n = 59 cases and n = 47 controls). Results for both **accuracy and RT in the HLJT** presented small heterogeneity ($I^2 = 0\%$; $\tau^2 = 0$, Q(1) = 1.13, p = 0.7158 and $I^2 = 0.7\%$; $\tau^2 = 0.0008$, Q(1) = 1.01, p = 31.56; respectively). There was no statistical evidence of impaired mental body transformation ability on both accuracy rate and RT in people living with PD compared to HCs, with a small effect size (SMD = -0.183 [-1.093; 0.726], t = -2.56, p = 0.2374 and SMD = 0.141 [-2.378; 2.661], t = 0.71, p = 0.6055; respectively for accuracy and RT; Figures 5D and 5E).

3.4.4 Qualitative synthesis of temporal congruence

In relation to mental chronometry, **moderate evidence** from 2 **case-control studies** (Avanzino et al., 2013; Cohen et al., 2011) with **moderate** and **low RoB** respectively, supports impaired mental chronometry ability. Another work (Scarpina et al., 2019) with **moderate RoB** found that for the left hand the time congruence is similar between cases and HCs but not for the right hand. This study is the only one that presented such results and could not be associated with an evidence category.

3.5 Multiple sclerosis

3.5.1 Studies and participants characteristics

Eleven studies were included (with n = 296 cases and n = 264 controls). Nine (81.82%) had a case-control design, 1 (9.09%) had a cross-sectional design and the last had an RCT design. The mean ± SD score of the JBI was 6.82 ± 1.25 points, with 8 and 3 studies rated as low and moderate RoB, respectively.

The cross-sectional and the RCT studies had both low RoB. Among case-control studies, 6 (66.67%) had a low RoB and 3 (33.33%) had a moderate RoB (Appendix 6).

Regarding participant's characteristics, the weigthed mean ± SD age was 38.37 ± 8.97 and 38.47 ± 9.73 for cases and controls respectively with a range of 44 to 70 years. There was a marked female predominance in the case group (66.22%) against 62.5% in the control group. Eligibility criteria encompassed for inclusion: having a definite diagnosis of the MS disease, belong to one subgroup of MS, having a stable condition of the disease in the last 3 months, being right-handed, having the Expanded Disability Status Scale (EDSS) score range between 0.5 and 3.5, normal or corrected-to-normal vision.

The exclusion criteria were: Mini-Mental State Examination (MMSE) score < 24, Fatigue Severity Scale (FSS) > 4, Beck Depression Inventory (BDI)-II > 21, recent relapse, neurological or psychiatric comorbidity, severe orthopaedic problems of the upper limb, related corticosteroid therapy within 8–12 weeks preceding study entry, chronic psychiatric disorders, alcohol or drug abuse, and treatment with deep stimulants.

Twelve studies explored explicit MI with more (58.33%) mental chronometry than questionnaire-based assessment methods (41.67%), while five explored implicit MI. The questionnaires used were KVIQ-20 (three studies) and KVIQ-10 (2 studies). Temporal congruence paradigms were the real and imagined Time Up and Go test, 10 meters walk test (2 studies each), Block and Box Test, Target Pointing task, Ball Squeezing task and Walking task. The mental rotation tasks were HLJT for 4 studies and a mixed HLJT-FLJT task for the last one.

3.5.2 Outcomes measured

For **implicit** MI, outcome measures were still homogeneous and reported as RT and accuracy/error rate.

Concerning **explicit** MI assessed by questionnaires, the reported outcomes were fairly homogeneous as they were provided by 2 versions of the same questionnaire (KVIQ). They were the kinesthetic imagery, the visual imagery and/or overall imagery vividness/generation ability. Mental chronometry outcomes were still heterogeneous (details below in Table 5).

Table 5: Characteristics of included studies for Multiple Sclerosis condition

Authors and design	RoB	JBI Score	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
(Allali et al., 2012) Case-control study	MODERATE	6	Explicit	TUG and iTUG	Delta time (%)	=	Preserved Mental Chronometry ability
(Nogueira et al., 2013) Case-control study	LOW	7	Explicit	10m-TWT and i-10m-TWT	Walking speed overestimation based on difference between real and imagined walking speed (%)	<	Impaired Mental Chronometry ability
(Azin et al., 2016) Case-control study	MODERATE	6	Implicit	HLJT and FLJT	Reaction time (millisecond)	<	Impaired Mental Rotation ability
					Accuracy (%)	<	
(Heremans, D'Hooge A, et al., 2012) Case-control study	LOW	7	Explicit	KVIQ-10	Total score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
			Implicit	HLJT	Accuracy (%)	<	Impaired Mental Rotation ability
(Kahraman et al., 2020) **RCT**	LOW	7	Explicit	KVIQ-10	Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score	=	
				TUG and iTUG	Delta time (%)	=	Preserved Mental Chronometry ability
				10m-TWT and i-10m-TWT	Delta time (%)	=	
(Salari et al., 2023) Case-control study	LOW	7	Explicit	KVIQ-20	Visual Imagery Score (%)	<	Impaired Vividness of Kinesthetic and Visual motor imagery
					Kinesthetic Imagery Score (%)	<	
				BBT and iBBT	Absolute time difference for right hand (min)	<	Impaired Mental Chronometry ability
					Absolute time difference for left hand (min)	<	
			Implicit	HLJT	Reaction time right hand (millisecond)	<	Preserved mental rotation ability but with slowness of motor planning
					Reaction time left hand (millisecond)	<	
					Accuracy right hand (%)	=	
					Accuracy left hand (%)	=	
(Tabrizi et al., 2014) Case-control study	LOW	9	Explicit	KVIQ-20	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
			Implicit	HLJT	Reaction time (millisecond)	<	Impaired Mental Rotation ability
					Accuracy (%)	<	
(Tabrizi et al., 2013) Case-control study	LOW	8	Implicit	HLJT	Reaction time (millisecond)	<	Impaired Mental Rotation ability
					Accuracy (%)	<	

RoB: Risk of Bias; **JBI**: Joanna Briggs Institute's checklist; **MI**: motor imagery; **KVIQ-20**: Kinesthetic and Visual Imagery Questionnaire-20 items; **KVIQ-10**: Kinesthetic and Visual Imagery Questionnaire-10 items; **HLJT**: Hand Laterality Judgment Task; **TUG**: Time up and Go Test; **iTUG**: imagined TUG; **10m-TWT**: 10 meter Timed Walk Test; **i-10m-TWT**:imagined 10 m-TWT; **BBT**: Box and Block Test; **iBBT**: imagined BBT; **HCs**: Healthy controls; **<**: cases are worse than HCs; **=**: cases are similar to HCs

Table 5 (continued)

Authors and design	Decision	JBI Score	MI Domain	Behavioural assessment task/tool	Outcomes measure	Performance direction	Summary (compared to HCs)
(Tacchino et al., 2013) Case-control study	MODERATE	4	Explicit	Real and Imagined pointing target task	Ratio of the duration of real and mental movements	<	Impaired Mental Chronometry ability
(Tacchino et al., 2018) Case-control study	LOW	7	Explicit	KVIQ-20	Total Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				Real and Imagined Squeezing ball task	Ratio of the number of real and imagined ball squeezes	<	Impaired Mental Chronometry ability
(Wajda et al., 2021) Cross-sectional study	LOW	7	Explicit	Real and imagined walking tasks	Absolute time difference between real and imagined Time	<	Impaired Mental Chronometry ability

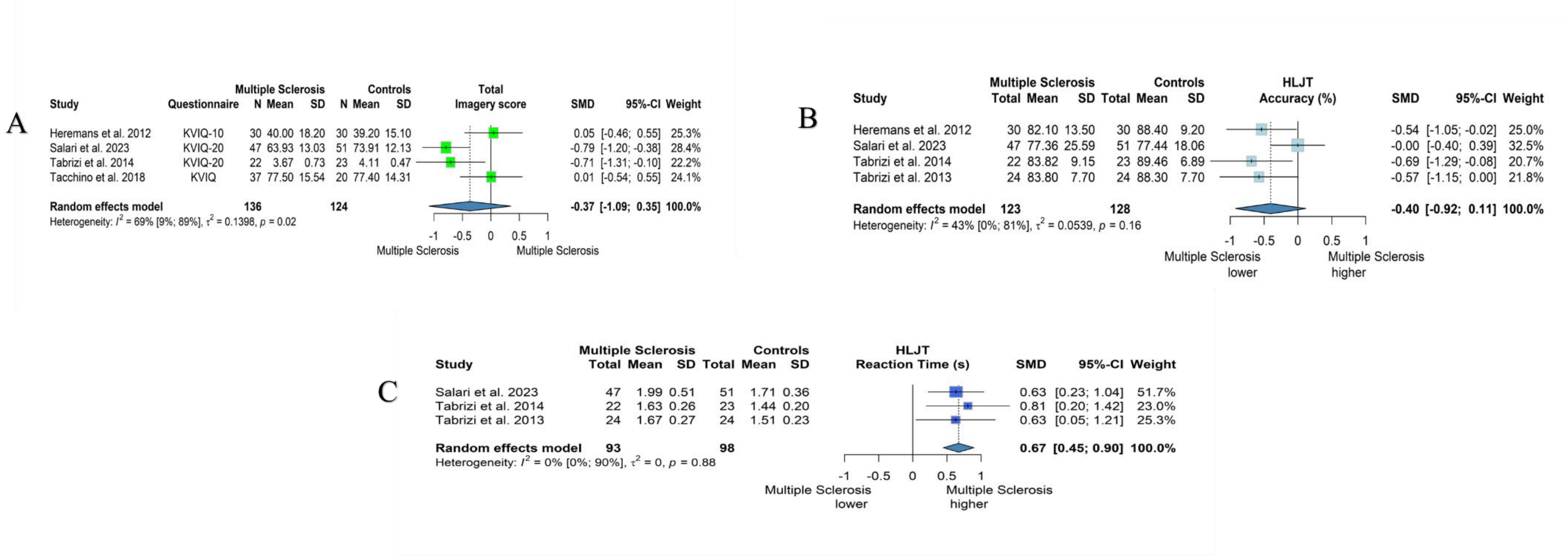


Fig. 6. Forest plots from quantitative analysis in Multiple Sclerosis for (**A**) total imagery, (**B**) accuracy and (**C**) reaction time

3.5.3 Quantitative synthesis

Explicit imagery

Regarding vividness of **visual** and **kinesthetic imagery**, the meta-analysis was not possible, because there were only 2 studies and one of them reported the statistics splitting by the two experimental groups, so it was not possible to include it. Unfortunately, the studies that measured mental chronometry were omitted again from the analyses, as the data could not be pooled.

However, out of the 5 studies that reported on the assessment by questionnaires, 4 gave the total score, which made it possible to carry out the meta-analysis. So, the meta-analysis run from them for **overall MI** ability included 260 participants, 136 cases and 124 controls. Results presented moderate heterogeneity ($I^2 = 68.6\%$ [9.0; 89.1%]; $\tau^2 = 0.1398$ [0.0013; 2.73], $Q(3) = 9.54$, $p = 0.0229$), with no evidence of publication bias ($t(2) = 0.63$, $p = 0.5907$). There was no statistical evidence of diminished MI ability for the overall vividness in people with MS compared to HCs, although a moderate effect size towards impaired MI was found (SMD = - 0.36 [-1.086; 0.351], $t = -1.63$, $p = 0.2022$; Figure 6A).

Implicit imagery

Regarding the **accuracy in the HLJT**, the meta-analysis included 4 studies (251 participants, n = 123 cases and n = 128 controls). Heterogeneity was moderate ($I^2 = 42.5\%$ [0.0; 80.7%]; $\tau^2 = 0.0539$ [0; 1.23], $Q(3) = 5.22$, $p = 0.1564$), without evidence of publication bias ($t(2) = -6.34$, $p = 0.240$). There was no statistical evidence of diminished mental body transformation ability on the accuracy rate in people with MS compared to HCs, although a moderate effect size was found (SMD = -0.4033 [-0.9212; 0.1145], $t = -2.48$, $p = 0.0894$; Figure 6B).

For the **RT in the HLJT**, 3 studies were included with a total of 191 participants. Of these, 93 were in the case group and 98 in the control group. The analysis revealed no heterogeneity between studies, with an I^2 value of 0% [0; 89.6%]; $\tau^2 = 0$ [0; 0.32]; $Q(2) = 0.25$, $p = 0.8846$ and no evidence of publication bias ($t(1) = 0.80$, $p = 0.5718$). On the other hand, there was a statistically significant difference between groups reflecting slower RT for mental body transformation with a moderate effect size (SMD = 0.6720 [0.4473; 0.8967]; $t = 12.87$, $p = 0.0060$; Figure 6C).

3.5.4 Qualitative synthesis

Visual and kinesthetic MI

Synthesis for these modalities concerned **2 studies, a case-control study** and **an RCT** with both **low RoB** which reported visual and kinesthetic MI ability.

They provided **contradictory evidence**. One (Kahraman et al., 2020) indicated a preserved vividness of visual and kinesthetic MI and the other (Salari et al., 2023) showed impaired ability for both modalities in people with MS compared to HCs.

Temporal congruence

Regarding mental chronometry, **strong evidence** from **4** studies (Nogueira et al., 2013; Salari et al., 2023; Tacchino et al., 2018) with low **RoB (3 case-control studies and 1 cross-sectional study)** and **1 moderate RoB case-control study** (Tacchino et al., 2013) indicated that, compared to HCs, patients with MS exhibit higher temporal incongruence between overt and covert movements. On the contrary, **moderate evidence** from **1 moderate RoB case-control study (Allali et al., 2012)** and **1 low RoB RCT** (Kahraman et al., 2017)**,** supported a preserved mental chronometry ability in MS patients.

3.6 Traumatic Brain Injury

3.6.1 Studies and participants characteristics

One case-control study (Oostra et al., 2012) was included, with n = 20 cases and n= 17 controls. The JBI score was 7 points out of 9 and was rated as **low RoB** (Appendix 8).

Regarding participant's characteristics, the mean ± SD age was 31.20 ± 12.30 and 32.10 ± 14.20 years for cases and controls, respectively. Males were more represented (16 in case group and 13 in the control group). Eligibility criteria were a normative level of consciousness with no posttraumatic amnesia.

MI assessment was made through questionnaire, mental chronometry and mental rotation methods. The questionnaire used was the MIQ-RS and mental chronometry tasks were the Time-Dependent Motor Imagery screening test, the Temporal

Congruence Stepping test and the Walking Trajectory test. Mental rotation task was the HLJT.

3.6.2 Outcomes measured

RT was the only outcome measured for the HLJT. Overall MI score was reported for MIQ-RS and there were 3 different outcomes for mental chronometry tasks (Table 6).

3.6.3 Qualitative synthesis

Explicit imagery

This **case-control study** with **low RoB** provided **moderate evidence** supporting a diminished vividness of overall MI after brain injury compared to HCs.
It also provided **moderate evidence** for a preserved mental chronometry ability, comparable to HCs.

Implicit imagery

For mental transformation ability, **moderate evidence** from **this study** indicated a slowness in the process of imagining the movements compared to HCs.

3.7 Cerebral Palsy

3.7.1 Studies and participants characteristics

Six case-control studies were included (n = 131 cases and n = 241 controls). The mean ± SD score of the JBI was 5.33 ± 0.82 points, and there were 5 studies (83.33%) rated as **moderate RoB** and the last one rated as **low RoB** (Appendix 7).

Regarding participant's characteristics, the weigthed mean ± SD age was 11.36 ± 4.06 and 10.11 ± 4.54 years for cases and controls, respectively ranged from 7 to 22 years. Male were more represented (54.95% in case group and 50.65% in the control group). Eligibility criteria were for inclusion: confirmed diagnosis of Unilateral Cerebral Palsy according to definition (MRI and clinical history); Intelligence Quotient > 70; presented mild or moderate upper-limb disability; no history of seizures or seizures well-controlled by therapy. For exclusion criteria, there were: presence of major visual and/or auditory deficits and drug treatment affecting the central nervous system; had a cognitive, visual or auditory impairments; had severe attention problems; not following task instructions.

Five studies explored explicit MI with more (60%) mental chronometry assessment than questionnaire-based methods (40%) and both (1 study). Three studies assessed implicit MI through the HLJT. The questionnaires used were VMIQ-2 and a modified version of Florida Praxis Imagery Questionnaire (1 study each). Temporal congruence paradigms were a Walking task, a Visual Movement task and a Hand Movement task.

3.7.2 Outcomes measured

RT and accuracy/error rate were the outcomes measured for the HLJT. Outcomes reported for the questionnaires were overall imagery, external visual imagery (third perspective) and kinesthetic imagery ability (more details in Table 7). Correlation coefficient and error timing rate were reported for mental chronometry tasks (more details in Table 7).

3.7.3 Quantitative synthesis

Unfortunately, the studies either did not report the data in an exploitable way or there is only one study per assessment task/questionnaire (Table 7) and therefore, the meta-analyses could not be run.

3.7.4 Qualitative synthesis

Explicit imagery

We found **limited evidence** from **2 case-control studies** (Galli et al., 2022; Lust et al., 2016) with **moderate RoB** that supported a preserved MI ability after CP. Note that the Florida Praxis Imagery Questionnaire used in Lust et al. (2016) measured MI through kinesthetic, position, action and object modalities whereas the VMIQ-2 measured kinesthetic and both internal and external visual modalities of MI (Suica et al., 2022).

Related to mental chronometry, **limited evidence** from **2 case-control studies** (Errante et al., 2019; Galli et al., 2022) with **moderate RoB** supported a preserved temporal congruence between overt and covert movement similarly to HCs.

Table 6 : Characteristics of included studies for Traumatic Brain Injury condition

Authors and design	RoB Decision	JBI Score	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
Oostra et al. 2012 Case-Control Study	LOW	7	Explicit	MIQ-RS	Total Score	<	Preserved Vividness of Kinesthetic and Visual motor imagery
				TDMI screening test	Correlation measure between real and imagined movement	=	Preserved Mental Chronometry ability
				Temporal congruence stepping test	Correlation measure between real and imagined movement	=	Preserved Mental Chronometry ability
				Walking trajectory test	Association measure between real and imagined movement	=	Preserved Mental Chronometry ability
			Implicit	HLJT	Reaction time (millisecond)	<	Impaired Mental Rotation ability

RoB: Risk of Bias; **JBI**: Joanna Briggs Institute's checklist; **MI**: motor imagery; **MIQ-RS**: Movement Imagery Questionnaire second revised version; **TDMI**: Time Dependant Motor Imagery; **HLJT**: Hand Laterality Judgement Task; **HCs**: Healthy controls; **<**: cases are worse than HCs; **=**: cases are similar to HCs

Table 7 : Characteristics of included studies for Cerebral Palsy condition

Authors and design	RoB Decision	MI Domain	Behavioural assessment task/tool	Outcome measures	Performance direction	Summary (compared to HCs)
(Crajé et al., 2010) Case-control study	MODERATE	Implicit	HLJT	Error rate (%)	=	Preserved Mental rotation ability
(Errante et al., 2019) Case-control study	MODERATE	Explicit	Imagined and Real Hand Movement	Pearson correlation coefficient between the average real and imagined movement durations	=	Preserved Mental Chronometry ability
(Galli et al., 2022) Case-control study	MODERATE	Explicit	VMIQ-2	External Visual Imagery Score	=	Preserved Vividness of Kinesthetic and Visual motor imagery
				Kinesthetic Imagery Score	=	
			Visual and Imagery Movement Task	Error rate Index	=	Preserved Mental Chronometry ability
(Lust et al., 2016) Case-control study	MODERATE	Explicit	Adapted FPIQ	Total Score	=	Preserved Praxis imagery ability
		Implicit	HLJT	Reaction time (millisecond)	<	Preserved mental rotation ability but with slowness of motor planning
				Number of error	=	
(Molina et al., 2015) Case-control study	MODERATE	Explicit	Imagined and Real Walking task	Pearson correlation coefficient between real and imagined movement durations in 04 conditions	= = < <	Preserved Mental Chronometry ability Impaired Mental Chronometry ability
(Souto et al., 2020) Case-control study	LOW	Implicit	HLJT	Reaction time (millisecond)	=	Impaired Mental Rotation ability
				Accuracy (%)	<	

RoB: Risk of Bias; **JBI**: Joanna Briggs Institute's checklist; **MI**: motor imagery; **HLJT**: Hand Laterality Judgement Task; **VMIQ-2**: Vividness of Movement Imagery Questionnaire second version; **FPIQ**: Florida Praxis Imagery Questionnaire; **HCs**: Healthy controls; **<**: cases are worse than HCs; **=**: cases are similar to HCs

However, (Molina et al., 2015), a **case control study** with **moderate RoB** reported that people with CP (hemiplegia and diplegia) demonstrated the same temporal invariance as HCs between executed and imagined walking only for shorter distance (4 meters) while impaired MI maintenance for longer distance (8 meters).

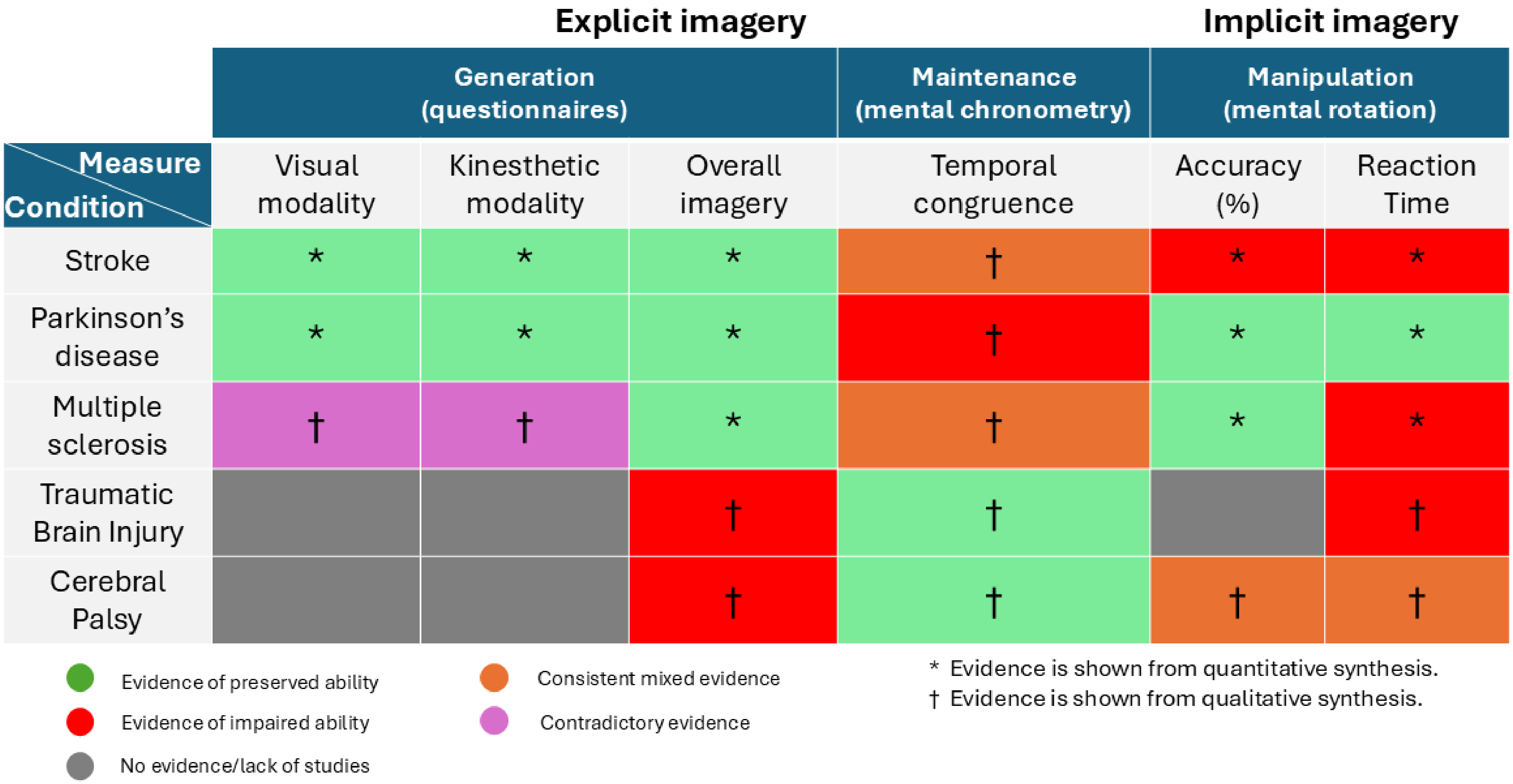
Implicit imagery

Two case-control studies (Crajé et al., 2010; Lust et al., 2016) with **moderate RoB** suggested **limited evidence** for a preserved mental body transformation ability, regarding accuracy. About RT, Lust et al. (2016) reported a slower reaction in the case group indicating a preserved mental rotation ability but with a slowness of motor planning.

Moderate evidence from **1 case-control study** (Souto et al., 2020) with **low RoB** supported an impaired mental body transformation ability with a diminished accuracy and normal RT.

3.8 Summary of the Evidence

Figure 7 shows the summary of all the evidence found regarding the differences in MI ability between people with central neurological conditions and healthy individuals.



	Explicit imagery				Implicit imagery	
	Generation (questionnaires)			Maintenance (mental chronometry)	Manipulation (mental rotation)	
Measure / Condition	Visual modality	Kinesthetic modality	Overall imagery	Temporal congruence	Accuracy (%)	Reaction Time
Stroke	🟩 *	🟩 *	🟩 *	🟧 †	🟥 *	🟥 *
Parkinson's disease	🟩 *	🟩 *	🟩 *	🟥 †	🟩 *	🟩 *
Multiple sclerosis	🟪 †	🟪 †	🟩 *	🟧 †	🟩 *	🟥 *
Traumatic Brain Injury	⬛	⬛	🟥 †	🟩 †	⬛	🟥 †
Cerebral Palsy	⬛	⬛	🟥 †	🟩 †	🟧 †	🟧 †

🟩 Evidence of preserved ability
🟥 Evidence of impaired ability
⬛ No evidence/lack of studies
🟧 Consistent mixed evidence
🟪 Contradictory evidence

* Evidence is shown from quantitative synthesis.
† Evidence is shown from qualitative synthesis.

Fig. 7. Summary of evidence for the differences in MI ability between all conditions and healthy individuals

4 DISCUSSION

This work aimed to collect and analyse evidence regarding differences in MI abilities in people with stroke, PD, MS, TBI and CP in comparison to healthy individuals. Our research methodology enabled us to gather low to moderate RoB studies among these conditions with a certain level of homogeneity between participants on several characteristics. The results of the different studies considered here circle around MI ability across behavioural assessment methods. Of course, heterogeneity due to sample characteristics, assessment tools and outcomes measures used may have influenced these results. In each study, HCs were matched to cases, and they were assessed in a similar way in almost all studies. Moreover, the fact that it was possible to carry out meta-analyses, although not for all conditions, constitutes one of the strengths of this systematic review. The results revealed preserved MI generation ability for all conditions except TBI, while evidence for mental transformation and image maintenance abilities was quite varied (see in Figure 7 above).

4.1 Explicit domain of MI

MI generation: questionnaires

In stroke, the trend was towards preserved ability to generate clear images and/or to feel realistic sensations from them, as well overall MI ability as kinesthetic and visual modalities. The same trend concerned PD for both modalities and overall MI. For MS condition, trend towards preservation was only about overall MI and the evidence about kinesthetic and visual MI ability was quite uncertain. This similarity between stroke on the one hand and PD and MS on the other is unexpected, given that PD and MS are neurodegenerative diseases and stroke an acquired injury. Nevertheless, it could be linked to a similar degree of relatively low motor impairment in the participants included. Unfortunately, the available data did not allow us to verify this, as there was inconsistent reporting and usage of outcome measures of motor impairment across studies. Overall MI ability seemed preserved in CP, like in the previous mentioned conditions, and impaired in TBI, but these findings reflected limited evidence because of the small number of papers. Further comparative studies under these conditions are needed.

Santoro et al. (2019), Kerry et al. (2016) and Fierro-Marrero et al. (2024) obtained similar results about preserved images generation ability in stroke, PD and CP conditions respectively.

On the contrary, Kerry et al. (2016) found a decreased MI vividness in stroke. This could be due to the brain regions affected in their included studies, but as few studies in our work reported that information, and therefore we could not extract it, this is a speculative explanation. Another explanation could be due to the decision rule of impaired MI used. Indeed, Kerry et al. (2016) used predefined cut-offs in their normalized MI Ability Assessment Scale (MAAS) in order to determine ability, impairment, or inability rather than comparison with matched HCs. These cut-offs were based on numerical ranges of various MI ability questionnaires scores and then, our quantitative approach of comparing patients versus HCs to collect evidence differs from theirs. As MI ability could be influenced by factors like age, gender and life experience with strength or weakness in some of its aspects without necessarily be impaired, using those cut-offs would not the best strategy, as they ignore these characteristics.

Mental chronometry

The evidence about the ability to maintain mental imagery over time with temporal congruence in relation to real movement, is mixed in stroke and MS conditions, although for PD the trend is towards impaired maintenance ability. These results could be explained by the wide variety of tasks used. However, for stroke and MS conditions, the strongest evidence was towards impaired MI compared to HCs. In stroke, damage to areas responsible for motor planning and execution could lead to discrepancies between imagined and actual performance and, considering the work of Liepert et al. (2012), association of sensory deficits could be a factor that increases this effect. Patients with MS exhibit not only motor, but also cognitive dysfunctions such cognitive fatigue, difficulties in attention and processing speed (Ghasemi et al., 2017) that could hinder the ability to maintain motor images over time. Furthermore, since one of the cardinal symptoms in PD is bradykinesia (i.e. slowness of executed movement), which is present in almost all patients, this slowness could affect MI too, leading to a temporal incongruence larger than in HCs. The findings in TBI and CP conditions supported a preserved ability to maintain MI, but this result could be largely influenced by the scarce number of studies, which again underlines the need of more studies in these conditions to draw up clearer evidence.

Evidence from Santoro et al. (2019) and Fierro-Marrero et al. (2024) showed respectively a trend to impaired maintenance imagery ability in stroke and preserved in CP. For the latter condtion, our finding was partially based on one paper also included by Fierro-Marrero et al. (2024). This could explain such similarity, although that temporal invariance could be remains only for short actions duration (Molina et al., 2015). Unlike our results, Kerry et al. (2016) reported evidence of temporal congruence in PD condition and this is likely also due to their decision based on normalized MI ability assessment for comparison mentioned above.

4.2 Implicit domain of MI

Regarding the implicit domain of MI, the evidence was less uniform. Mental body transformation ability was impaired in stroke (both accuracy and RT), in TBI (RT only reported) and in MS for RT (but preserved performance in terms of accuracy). On the contrary in PD, there was a trend towards preservation for both accuracy and RT. For CP, the evidence was mixed for both accuracy and RT. The slower RT observed in stroke and MS could be an adaptation to the present state of the neural network in order to preserve performance. But here, for RT in the HLJT, we do not know to what extent a slowness in the case group can be attributed to the task itself (slowness specific to MI processing), or to their injured nervous system (i.e. they are slower overall). In the case of a task-specific effect, the fact that accuracy was still worse in stroke compared to HCs and not in MS, maybe due to age and gender differences as the majority of participants in the MS studies were female and were younger than stroke participants. Schott (2012) and Subirats et al. (2018) reported better performance in MI for younger people and women, respectively, which is consistent with this idea. Moreover, there is no specific evidence for altered body-schema in neurodegenerative disease like MS and PD to our knowledge. For PD, the fact that mental body transformation ability is preserved could be also due to a less altered body-schema in this population.

Santoro et al. (2019) and Di Rienzo et al. (2014) reported same effects for stroke and PD conditions. For Di Rienzo et al. (2014), patients with PD condition could still perform implicit imagery tasks, and the tremor symptom may facilitate certain neural adaptations that support MI processing.

They also suggested that patients with stroke may show impaired cognitive processing during implicit MI tasks, which is likely associated with reduced activity in frontal, central, and parietal regions of the brain. For CP, there is similar incongruity in the work of Fierro-Marrero et al. (2024) about accuracy performance, but both in our work and in theirs, the strongest evidence trending to poorer accuracy and preserved RT. But again, the lack of studies and data reduces the certainty of this result.

Altogether, regarding the domains of MI, we just found one systematic review for MS (Seebacher et al., 2023) which reported that, MI maintenance and transformation ability could be impaired and were associated to deficits in cognitive function. We should also consider that, for the implicit domain of MI, only few studies reported the presence of the biomechanical constraints effect which is regarded as a behavioural feature of performing MI of body parts.

4.3 Limitations

There are limitations arising from the original studies included in this work. These include the small sample sizes of original studies and the wide variety of MI measures, especially for mental chronometry but also questionnaires. For mental chronometry, this heterogeneity impeded to perform a quantitative synthesis. In addition, the limited number of studies for TBI, CP, but also MS conditions and the lack of exploitable data in several studies are clear limitations of this work, as it impeded their inclusion in the meta-analyses. Besides, the wide heterogeneity on the motor function scales/assessments and the lack of their reporting, impeded to investigate this as a factor conditioning MI ability through a meta-regression. Furthermore, about the biomechanical constraints effect in the HLJT and the FLJT, it is worth noting that few studies have addressed this fact, reported statistical data to check whether it was present, or some studies reported its absence. This has limited the possibility of drawing any real conclusions about MI manipulation in these studies. There are also limitations from our research itself. Indeed, some of the paper retrieved for search strategy measured mental imagery rather than specific MI, or reported results in figures rather than data itself. Moreover, we did not manage to get the full-texts for several studies.

All these limitations mentioned pose challenges for detecting the true magnitude of differences between groups and establishing a clear direction of the effect, especially for mental chronometry. Nevertheless, a consistent direction could be ascertained for the ability to generate images and related sensations in stroke and PD.

In order to improve the strength of future reviews, we suggest further comparative studies, especially in MS, TBI and CP with good quality of reporting. That include a consensus for the motor function scale that should be used in each condition and the biomechanical constraints effect. We also suggest a standardisation of mental chronometry assessment, for example the selection and validation by neurological conditions of 1 or 2 tasks for the upper limb and the same for the lower limb or the whole body. It will also benefit to standardise the outcome measure of temporal congruence for these chronometric tests.

4.4 Clinical implications

Our findings suggest that stroke patients could benefit of MI therapy based on visual, but also kinesthetic modalities, implying so, benefits for both perspectives. These modalities could improve motor function, but we think that kinesthetic practice could be more efficient because not only it stimulates motor pathways but also the body schema and sensory awareness. That may provide a gateway for helping the altered mental transformation ability, although this is yet to be formally tested.

Like stroke patients, people with PD could benefit of MI therapy targeting imagery generation, whatever the modality employed. However, the therapeutic implementation may be larger because they have a preserved mental body rotation ability. The same therapeutic implementation for PD patients concerns those with MS, except that we have less information about image generation training, and which of the visual or kinesthetic modalities will be the easiest approach.

5 CONCLUSION

Currently, few studies explored MI ability in subjects with neurological conditions compared to HCs. Compared to HCs, some aspects of MI ability seems to be reduced in patients with neurological disorders. More specifically, following our analysis, stroke subjects present deficits in mental rotation and temporal congruence. This temporal congruence is also affected in PD and MS patients. On the other hand, there is some evidence that CP patients have a reduced ability of mental body transformation. Due to the lack of studies in TBI, clear conclusion cannot be draw. The present review showed several limitations and among others the most impactful were the small number of papers in the CP and TBI conditions, the lack of reporting motor disability and imagery data and the diversity of tasks assessing mental chronometry which prevented from doing the quantitative analyses. These different limitations make it difficult to establish a clear direction for our results. Further good quality comparative studies are needed to improve the strength of evidence.

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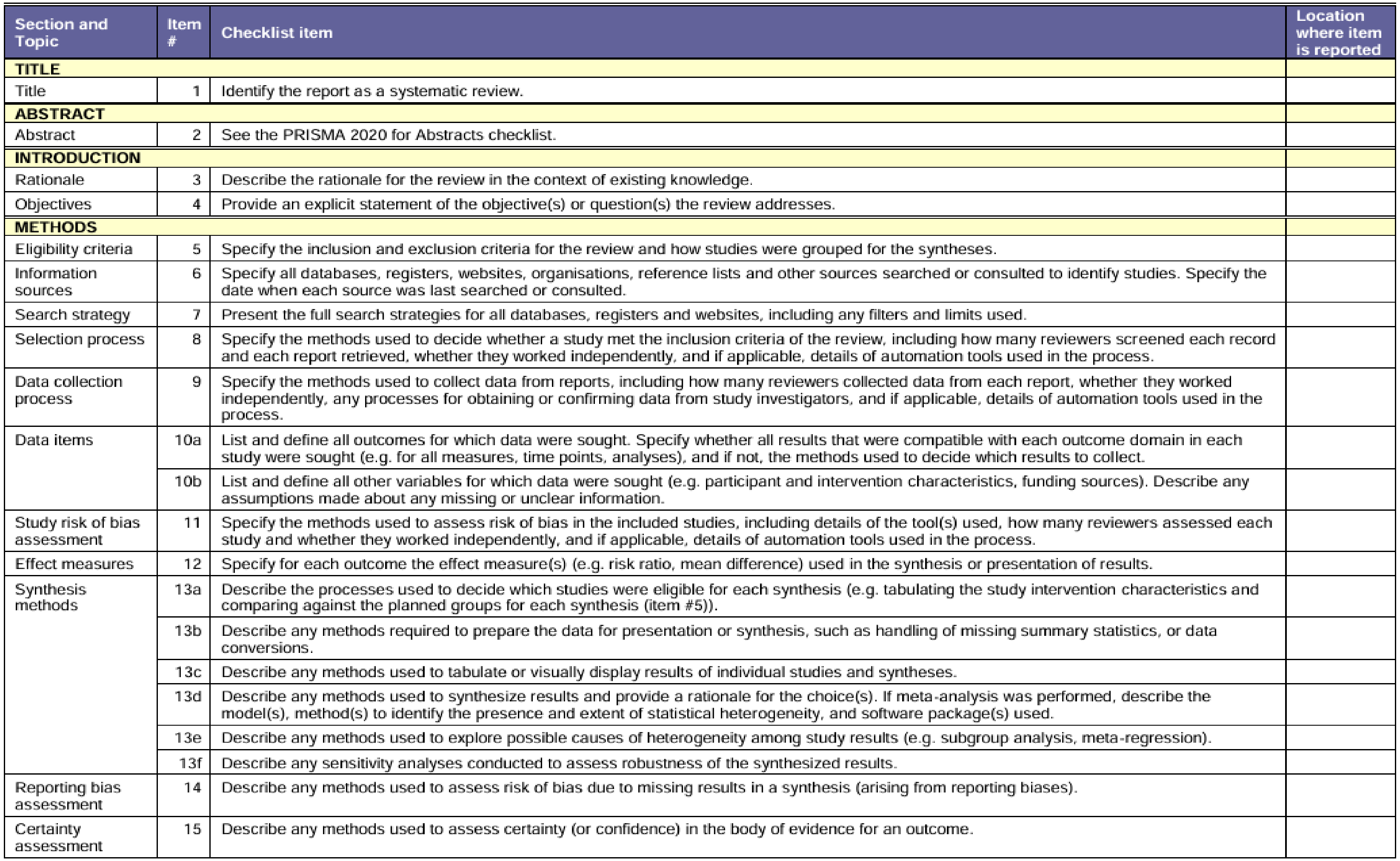
7 APPENDIX

Appendix 1: PRISMA Checklist



Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	
Study characteristics	17	Cite each included study and present its characteristics.	
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	
	23b	Discuss any limitations of the evidence included in the review.	
	23c	Discuss any limitations of the review processes used.	
	23d	Discuss implications of the results for practice, policy, and future research.	
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	
Competing interests	26	Declare any competing interests of review authors.	
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	

Appendix 2: Search strategy for all databases

EMBASE 1537

('central nervous system disease'/exp OR 'cns disease':ti,ab,kw OR 'cns disorder':ti,ab,kw OR 'central nervous system disease':ti,ab,kw OR 'central nervous system disorder':ti,ab,kw OR 'cerebrovascular accident'/exp OR 'cva':ti,ab,kw OR 'acute stroke':ti,ab,kw OR 'cerebral vascular accident':ti,ab,kw OR 'cerebrovascular injury':ti,ab,kw OR 'stroke':ti,ab,kw OR 'stroke patient'/exp OR 'stroke sufferer':ti,ab,kw OR 'cerebral palsy'/exp OR 'brain palsy':ti,ab,kw OR 'cerebral palsy':ti,ab,kw OR 'cerebral paresis':ti,ab,kw OR 'spastic diplegia':ti,ab,kw OR 'alzheimer disease'/exp OR 'alzheimer dementia':ti,ab,kw OR 'alzheimer disease':ti,ab,kw OR 'alzheimer`s disease':ti,ab,kw OR 'dementia, alzheimer':ti,ab,kw OR 'parkinson disease'/exp OR 'lewy bodies of parkinson disease':ti,ab,kw OR 'lewy bodies of parkinson`s disease':ti,ab,kw OR 'parkinson`s disease':ti,ab,kw OR 'paralysis agitans':ti,ab,kw OR 'amyotrophic lateral sclerosis'/exp OR 'als (amyotrophic lateral sclerosis)':ti,ab,kw OR 'lou gehrig`s disease':ti,ab,kw OR 'amyotrophic lateral sclerosis':ti,ab,kw OR 'parkinsonism':ti,ab,kw OR 'multiple sclerosis'/exp OR 'ms (multiple sclerosis)':ti,ab,kw OR 'disseminated sclerosis':ti,ab,kw OR 'multiple sclerosis':ti,ab,kw OR 'sclerosis, multiple':ti,ab,kw OR 'traumatic brain injury'/exp OR 'brain trauma':ti,ab,kw OR 'cerebral trauma':ti,ab,kw OR 'traumatic brain injuries':ti,ab,kw OR 'traumatic encephalopathy':ti,ab,kw OR 'spinal cord injury'/exp OR 'spinal cord injuries':ti,ab,kw OR 'spinal cord injury':ti,ab,kw OR 'phantom pain'/exp OR 'phantom limb pain':ti,ab,kw OR 'complex regional pain syndrome'/exp OR 'complex regional pain syndromes':ti,ab,kw OR 'chronic pain'/exp OR 'chronic pain':ti,ab,kw OR 'pain, chronic':ti,ab,kw) AND ('imagery'/exp OR 'imagery':ti,ab,kw OR 'guided imagery'/exp OR 'guided imagery':ti,ab,kw OR 'psychotherapy imagery':ti,ab,kw OR 'imagery rehearsal therapy'/exp OR 'motor imagery'/exp OR 'mental imagery'/exp OR 'imagery rehearsal therapy':ti,ab,kw OR 'motor imagery':ti,ab,kw OR 'mental imagery':ti,ab,kw OR 'movement imagery':ti,ab,kw OR 'action imagery':ti,ab,kw) AND ('case control study'/exp OR 'case control study':ti,ab,kw OR 'matched case control':ti,ab,kw OR 'experimental study'/exp OR 'experimental studies':ti,ab,kw OR 'experimental study':ti,ab,kw OR 'controlled study'/exp OR 'control group trial':ti,ab,kw OR 'controlled study':ti,ab,kw OR 'controlled trial':ti,ab,kw OR 'normal human'/exp OR 'healthy adult':ti,ab,kw OR 'healthy people':ti,ab,kw OR 'healthy subjects':ti,ab,kw OR 'healthy volunteer':ti,ab,kw OR 'healthy volunteers':ti,ab,kw OR 'normal human':ti,ab,kw OR 'normal subjects':ti,ab,kw OR 'controlled clinical trial (topic)'/exp OR 'controlled clinical trial (topic)':ti,ab,kw OR 'controlled clinical trials':ti,ab,kw OR 'controlled clinical trials as topic':ti,ab,kw OR 'non randomized controlled trials as topic':ti,ab,kw OR 'non-randomized controlled trials as topic':ti,ab,kw)

PUBMED 397

("central nervous system diseases"[MeSH Terms] OR "stroke"[MeSH Terms] OR "alzheimer disease"[MeSH Terms] OR "parkinson disease"[MeSH Terms] OR "amyotrophic lateral sclerosis"[MeSH Terms] OR "multiple sclerosis"[MeSH Terms] OR "brain injuries, traumatic"[MeSH Terms] OR "spinal cord injuries"[MeSH Terms] OR "cerebral palsy"[MeSH Terms] OR "phantom limb"[MeSH Terms] OR "complex regional pain syndromes"[MeSH Terms] OR "central nervous system diseases"[Title/Abstract] OR "stroke"[Title/Abstract] OR "cerebrovascular accident"[Title/Abstract] OR "alzheimer disease"[Title/Abstract] OR "alzheimer's disease"[Title/Abstract] OR "parkinson disease"[Title/Abstract] OR "parkinson's disease"[Title/Abstract] OR "amyotrophic lateral sclerosis"[Title/Abstract] OR "multiple sclerosis"[Title/Abstract] OR "traumatic brain injur*"[Title/Abstract] OR "spinal cord injur*"[Title/Abstract] OR "cerebral palsy"[Title/Abstract] OR "phantom limb"[Title/Abstract] OR "crps"[Title/Abstract] OR "chronic pain"[MeSH Terms] OR "chronic pain"[Title/Abstract]) AND ("imagery, psychotherapy"[MeSH Terms] OR "imagery"[Title/Abstract] OR "guided imagery"[Title/Abstract] OR "motor imagery"[Title/Abstract] OR "imagery rehearsal therapy"[Title/Abstract] OR "mental imagery"[Title/Abstract] OR "movement imagery"[Title/Abstract] OR "action imagery"[Title/Abstract]) AND ("case control studies"[MeSH Terms] OR "case control stud*"[Title/Abstract] OR "matched case control"[Title/Abstract] OR "experimental study"[Title/Abstract] OR "controlled study"[Title/Abstract] OR "control group trial"[Title/Abstract] OR "clinical trials as topic"[MeSH Terms] OR "controlled trial"[Title/Abstract] OR "normal human"[Title/Abstract] OR "normal subjects"[Title/Abstract] OR "healthy volunteers"[MeSH Terms] OR "healthy subjects"[Title/Abstract] OR "non randomized controlled trials as topic"[MeSH Terms] OR "non randomized controlled trials as topic"[Title/Abstract])

COCHRANE LIBRARY 469

#1 (cns disease):ti,ab,kw OR (cns disorder):ti,ab,kw OR (central nervous system disease):ti,ab,kw OR (central nervous system disorder):ti,ab,kw OR ("CVA"):ti,ab,kw (Word variations have been searched)
#2 (acute stroke):ti,ab,kw OR (cerebral vascular accident):ti,ab,kw OR (cerebrovascular injury):ti,ab,kw OR (stroke):ti,ab,kw OR (stroke sufferer):ti,ab,kw (Word variations have been searched)
#3 (brain palsy):ti,ab,kw OR ("cerebral palsy"):ti,ab,kw OR ("cerebral paralysis"):ti,ab,kw OR ("spastic diplegia"):ti,ab,kw OR ("Alzheimer dementia"):ti,ab,kw (Word variations have been searched)
#4 ("Alzheimer disease"):ti,ab,kw OR (Alzheimer's disease):ti,ab,kw OR (dementia, alzheimer):ti,ab,kw OR (lewy bodies of parkinson disease):ti,ab,kw OR (lewy bodies of parkinson's disease):ti,ab,kw (Word variations have been searched)
#5 (ALS (amyotrophic lateral sclerosis)):ti,ab,kw OR ("Lou Gehrig's disease"):ti,ab,kw OR ("amyotrophic lateral sclerosis"):ti,ab,kw OR ("parkinsonism"):ti,ab,kw OR (MS (Multiple Sclerosis)):ti,ab,kw (Word variations have been searched)
#6 ("disseminated sclerosis"):ti,ab,kw OR (cerebral trauma):ti,ab,kw OR ("multiple sclerosis"):ti,ab,kw OR (sclerosis, multiple):ti,ab,kw OR (brain trauma):ti,ab,kw (Word variations have been searched)
#7 ("traumatic brain injuries"):ti,ab,kw OR ("traumatic encephalopathy"):ti,ab,kw OR ("spinal cord injuries"):ti,ab,kw OR ("spinal cord injury"):ti,ab,kw OR ("phantom limb pain"):ti,ab,kw (Word variations have been searched)
#8 ("complex regional pain syndrome"):ti,ab,kw OR ("chronic pain"):ti,ab,kw OR (pain, chronic):ti,ab,kw (Word variations have been searched)
#9 (psychotherapy imagery):ti,ab,kw OR (imagery rehearsal therapy):ti,ab,kw OR (motor imagery):ti,ab,kw OR (mental imagery):ti,ab,kw OR ("imagery"):ti,ab,kw (Word variations have been searched)
#10 ("guided imagery"):ti,ab,kw OR (movement imagery questionnaire):ti,ab,kw OR (imagery questionnaire):ti,ab,kw AND (imagery ability):ti,ab,kw AND (mental chronometry):ti,ab,kw (Word variations have been searched)
#11 ("case control study"):ti,ab,kw OR (matched case control):ti,ab,kw OR ("experimental studies"):ti,ab,kw OR ("experimental study"):ti,ab,kw OR (controlled trial):ti,ab,kw (Word variations have been searched)
#12 (healthy adult):ti,ab,kw OR (healthy people):ti,ab,kw OR (healthy subjects):ti,ab,kw OR (healthy volunteer):ti,ab,kw OR (healthy volunteers):ti,ab,kw (Word variations have been searched)
#13 ("healthy control"):ti,ab,kw OR (normal human):ti,ab,kw OR ("normal subject"):ti,ab,kw OR ("controlled clinical trial"):ti,ab,kw OR ("non-randomized control trials"):ti,ab,kw (Word variations have been searched)
#14 MeSH descriptor: [Central Nervous System Diseases] explode all trees
#15 MeSH descriptor: [Stroke] explode all trees
#16 MeSH descriptor: [Cerebral Palsy] explode all trees
#17 MeSH descriptor: [Alzheimer Disease] explode all trees
#18 MeSH descriptor: [Parkinson Disease] explode all trees
#19 MeSH descriptor: [Amyotrophic Lateral Sclerosis] explode all trees
#20 MeSH descriptor: [Multiple Sclerosis] explode all trees

#21 MeSH descriptor: [Brain Injuries, Traumatic] explode all trees
#22 MeSH descriptor: [Spinal Cord Injuries] explode all trees
#23 MeSH descriptor: [Phantom Limb] explode all trees
#24 MeSH descriptor: [Complex Regional Pain Syndromes] explode all trees
#25 MeSH descriptor: [Chronic Pain] explode all trees
#26 MeSH descriptor: [Imagery, Psychotherapy] explode all trees
#27 MeSH descriptor: [Mentalization] explode all trees
#28 MeSH descriptor: [Case-Control Studies] explode all trees
#29 MeSH descriptor: [Non-Randomized Controlled Trials as Topic] explode all trees
#30 MeSH descriptor: [Randomized Controlled Trials as Topic] explode all trees
#31 MeSH descriptor: [Randomized Controlled Trial] explode all trees
#32 MeSH descriptor: [Healthy Volunteers] explode all trees
#33 MeSH descriptor: [Controlled Clinical Trial] explode all trees
#34 {OR #1-#8, #14-#25}
#35 #9 OR #10 OR #26 OR #27
#36 {OR #11-#13, #28-#33}
#37 {AND #34-#36}

SCOPUS 414

(INDEXTERMS ("cerebral palsy" OR "central nervous system diseases" OR "stroke" OR "alzheimer disease" OR "parkinson disease" OR "amyotrophic lateral sclerosis" OR "multiple sclerosis" OR "brain injuries, traumatic" OR "spinal cord injuries" OR "chronic pain" OR "phantom limb" OR "complex regional pain syndromes") OR TITLE-ABS-KEY ("cerebral palsy" OR "central nervous system diseases" OR "stroke" OR "alzheimer disease" OR "parkinson disease" OR "amyotrophic lateral sclerosis" OR "multiple sclerosis" OR "brain injuries, traumatic" OR "spinal cord injuries" OR "chronic pain" OR "phantom limb" OR "crps")) AND (INDEXTERMS ("imagery, psychotherapy" OR "imagery" OR "guided imagery" OR "motor imagery" OR "imagery rehearsal therapy" OR "mental imagery" OR "movement imagery" OR "action imagery") OR TITLE-ABS-KEY ("imagery, psychotherapy" OR "imagery" OR "guided imagery" OR "motor imagery" OR "imagery rehearsal therapy" OR "mental imagery" OR "movement imagery" OR "action imagery")) AND (INDEXTERMS ("case control studies" OR "clinical trials as topic" OR "healthy volunteers" OR "non randomized controlled trials as topic") OR TITLE-ABS ("case control stud*" OR "matched case control" OR "experimental study" OR "controlled study" OR "control group trial" OR "controlled trial" OR "normal human" OR "normal subjects" OR "healthy subjects" OR "non randomized controlled trials as topic")) AND (LIMIT-TO (SUBJAREA , "medi") OR LIMIT-TO (SUBJAREA , "neur") OR LIMIT-TO (SUBJAREA , "heal"))

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((MH "central nervous system diseases+") OR (MH stroke+) OR (MH "alzheimer disease+") OR (MH "parkinson disease+") OR (MH "amyotrophic lateral sclerosis+") OR (MH "multiple sclerosis+") OR (MH "brain injuries, traumatic+") OR (MH "spinal cord injuries+") OR (MH "cerebral palsy+") OR (MH "phantom limb+") OR (MH "complex regional pain syndromes+") OR (TI "central nervous system diseases" OR AB "central nervous system diseases") OR (TI stroke OR AB stroke) OR (TI "cerebrovascular accident" OR AB "cerebrovascular accident") OR (TI "alzheimer disease" OR AB "alzheimer disease") OR (TI "alzheimer's disease" OR AB "alzheimer's disease") OR (TI "parkinson disease" OR AB "parkinson disease") OR (TI "parkinson's disease" OR AB "parkinson's disease") OR (TI "amyotrophic lateral sclerosis" OR AB "amyotrophic lateral sclerosis") OR (TI "multiple sclerosis" OR AB "multiple sclerosis") OR (TI "traumatic brain injur*" OR AB "traumatic brain injur*") OR (TI "spinal cord injur*" OR AB "spinal cord injur*") OR (TI "cerebral palsy" OR AB "cerebral palsy") OR (TI "phantom limb" OR AB "phantom limb") OR (TI crps OR AB crps) OR (MH "chronic pain+") OR (TI "chronic pain" OR AB "chronic pain")) AND ((MH "imagery, psychotherapy+") OR (TI imagery

OR AB imagery) OR (TI "guided imagery" OR AB "guided imagery") OR (TI "motor imagery" OR AB "motor imagery") OR (TI "imagery rehearsal therapy" OR AB "imagery rehearsal therapy") OR (TI "mental imagery" OR AB "mental imagery") OR (TI "movement imagery" OR AB "movement imagery") OR (TI "action imagery" OR AB "action imagery")) AND ((MH "case control studies+") OR (TI "case control stud*" OR AB "case control stud*") OR (TI "matched case control" OR AB "matched case control") OR (TI "experimental study" OR AB "experimental study") OR (TI "controlled study" OR AB "controlled study") OR (TI "control group trial" OR AB "control group trial") OR (MH "clinical trials as topic+") OR (TI "controlled trial" OR AB "controlled trial") OR (TI "normal human" OR AB "normal human") OR (TI "normal subjects" OR AB "normal subjects") OR (MH "healthy volunteers+") OR (TI "healthy subjects" OR AB "healthy subjects") OR (MH "non randomized controlled trials as topic+") OR (TI "non randomized controlled trials as topic" OR AB "non randomized controlled trials as topic"))

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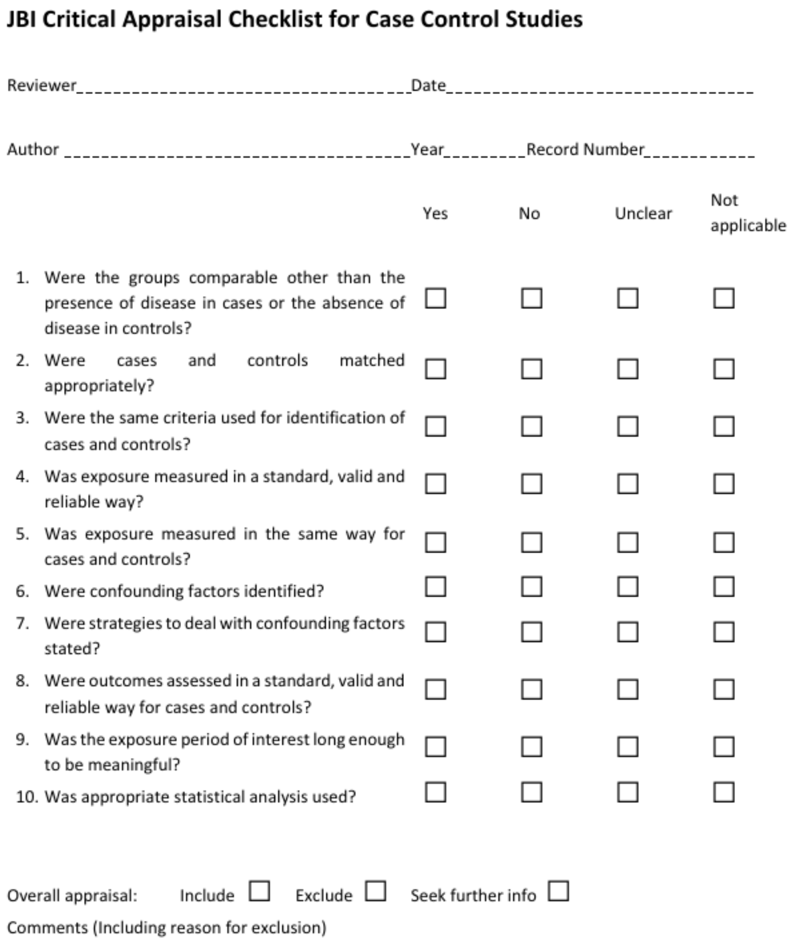
(MAINSUBJECT.EXACT.EXPLODE("Central Nervous System Disorders") OR MAINSUBJECT.EXACT.EXPLODE("Cerebrovascular Accidents") OR MAINSUBJECT.EXACT.EXPLODE("Alzheimer's Disease") OR MAINSUBJECT.EXACT.EXPLODE("Parkinson's Disease") OR MAINSUBJECT.EXACT.EXPLODE("Parkinsonism") OR MAINSUBJECT.EXACT.EXPLODE("Amyotrophic Lateral Sclerosis") OR MAINSUBJECT.EXACT.EXPLODE("Multiple Sclerosis") OR MAINSUBJECT.EXACT.EXPLODE("Traumatic Brain Injury") OR MAINSUBJECT.EXACT.EXPLODE("Spinal Cord Injuries") OR MAINSUBJECT.EXACT.EXPLODE("Cerebral Palsy") OR MAINSUBJECT.EXACT.EXPLODE("Phantom Limbs") OR MAINSUBJECT.EXACT.EXPLODE("Complex Regional Pain Syndrome (Type I)") OR MAINSUBJECT.EXACT.EXPLODE("Neuralgia") OR MAINSUBJECT.EXACT.EXPLODE("Chronic Pain") OR TI,AB("central nervous system disorders") OR TI,AB(stroke) OR TI,AB("cerebrovascular accident") OR TI,AB("alzheimer disease") OR TI,AB("alzheimer's disease") OR TI,AB("parkinson disease") OR TI,AB("parkinson's disease") OR TI,AB("parkinsonism") OR TI,AB("amyotrophic lateral sclerosis") OR TI,AB("multiple sclerosis") OR TI,AB("traumatic brain injur*") OR TI,AB("spinal cord injur*") OR TI,AB ("cerebral palsy") OR TI,AB("phantom limb") OR TI,AB(crps) OR TI,AB("chronic pain")) AND (MAINSUBJECT.EXACT.EXPLODE("Guided Imagery") OR MAINSUBJECT.EXACT.EXPLODE("Mental Rotation") OR TI,AB(imagery) OR TI,AB("guided imagery") OR TI,AB("motor imagery") OR TI,AB("imagery rehearsal therapy") OR TI,AB("mental imagery") OR TI,AB("movement imagery") OR TI,AB("action imagery")) AND (MAINSUBJECT.EXACT.EXPLODE("Randomized Clinical Trials") OR MAINSUBJECT.EXACT.EXPLODE("Clinical Trials") OR MAINSUBJECT.EXACT.EXPLODE("Experimental Design") OR MAINSUBJECT.EXACT.EXPLODE("Experiment Controls") OR TI,AB("case control stud*") TI,AB("case-control stud*") OR TI,AB("matched case-control") OR TI,AB("matched case control") OR TI,AB("experimental study") OR TI,AB("controlled study") OR TI,AB("control group trial") OR TI,AB("controlled trial") OR TI,AB("normal human") OR TI,AB("normal subjects") OR TI,AB("healthy subjects") OR TI,AB("non randomized controlled trials as topic"))

Appendix 3: Joanna Briggs Institute's (JBI) Critical appraisal checklist for Case-control studies



JBI Critical Appraisal Checklist for Case Control Studies

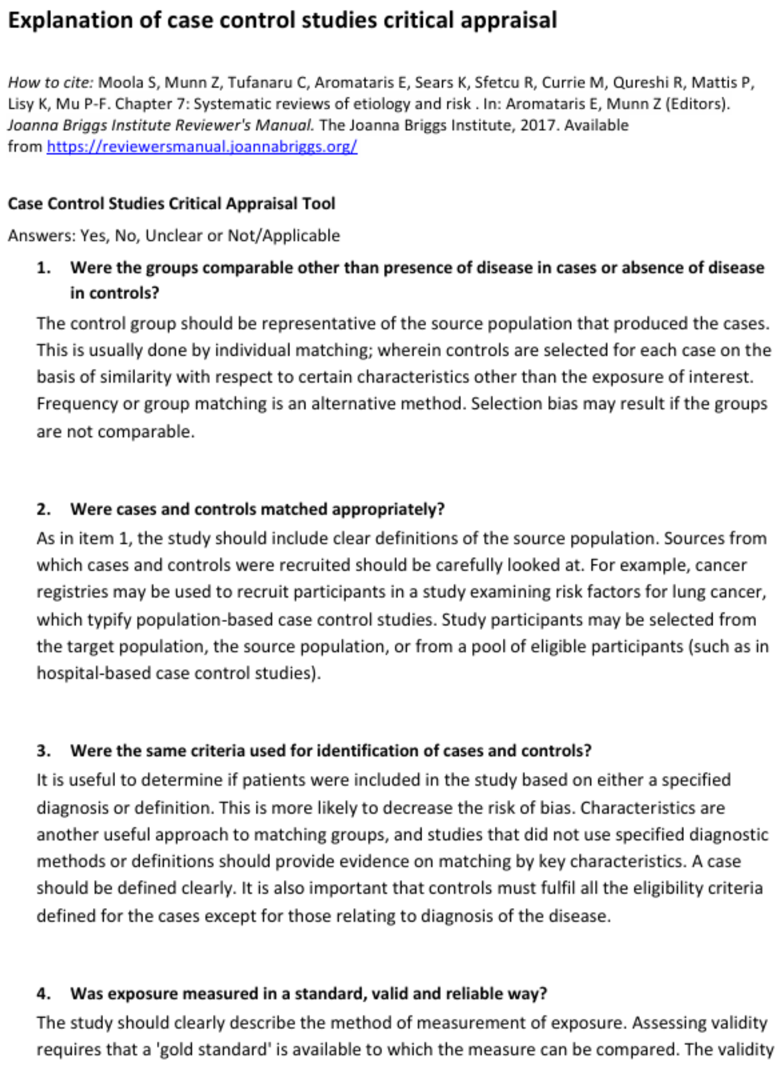
Reviewer_____________________________________Date_________________________________

Author ______________________________________Year_________Record Number____________

	Yes	No	Unclear	Not applicable
1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	☐	☐	☐	☐
2. Were cases and controls matched appropriately?	☐	☐	☐	☐
3. Were the same criteria used for identification of cases and controls?	☐	☐	☐	☐
4. Was exposure measured in a standard, valid and reliable way?	☐	☐	☐	☐
5. Was exposure measured in the same way for cases and controls?	☐	☐	☐	☐
6. Were confounding factors identified?	☐	☐	☐	☐
7. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?	☐	☐	☐	☐
9. Was the exposure period of interest long enough to be meaningful?	☐	☐	☐	☐
10. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)



Explanation of case control studies critical appraisal

How to cite: Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetcu R, Currie M, Qureshi R, Mattis P, Lisy K, Mu P-F. Chapter 7: Systematic reviews of etiology and risk . In: Aromataris E, Munn Z (Editors). *Joanna Briggs Institute Reviewer's Manual.* The Joanna Briggs Institute, 2017. Available from https://reviewersmanual.joannabriggs.org/

Case Control Studies Critical Appraisal Tool

Answers: Yes, No, Unclear or Not/Applicable

1. Were the groups comparable other than presence of disease in cases or absence of disease in controls?

The control group should be representative of the source population that produced the cases. This is usually done by individual matching; wherein controls are selected for each case on the basis of similarity with respect to certain characteristics other than the exposure of interest. Frequency or group matching is an alternative method. Selection bias may result if the groups are not comparable.

2. Were cases and controls matched appropriately?

As in item 1, the study should include clear definitions of the source population. Sources from which cases and controls were recruited should be carefully looked at. For example, cancer registries may be used to recruit participants in a study examining risk factors for lung cancer, which typify population-based case control studies. Study participants may be selected from the target population, the source population, or from a pool of eligible participants (such as in hospital-based case control studies).

3. Were the same criteria used for identification of cases and controls?

It is useful to determine if patients were included in the study based on either a specified diagnosis or definition. This is more likely to decrease the risk of bias. Characteristics are another useful approach to matching groups, and studies that did not use specified diagnostic methods or definitions should provide evidence on matching by key characteristics. A case should be defined clearly. It is also important that controls must fulfil all the eligibility criteria defined for the cases except for those relating to diagnosis of the disease.

4. Was exposure measured in a standard, valid and reliable way?

The study should clearly describe the method of measurement of exposure. Assessing validity requires that a 'gold standard' is available to which the measure can be compared. The validity of exposure measurement usually relates to whether a current measure is appropriate or whether a measure of past exposure is needed.

Case control studies may investigate many different ‘exposures’ that may or may not be associated with the condition. In these cases, reviewers should use the main exposure of interest for their review to answer this question when using this tool at the study level.

Reliability refers to the processes included in an epidemiological study to check repeatability of measurements of the exposures. These usually include intra-observer reliability and inter-observer reliability.

5. Was exposure measured in the same way for cases and controls?

As in item 4, the study should clearly describe the method of measurement of exposure. The exposure measures should be clearly defined and described in detail. Assessment of exposure or risk factors should have been carried out according to same procedures or protocols for both cases and controls.

6. Were confounding factors identified?

Confounding has occurred where the estimated intervention exposure effect is biased by the presence of some difference between the comparison groups (apart from the exposure investigated/of interest). Typical confounders include baseline characteristics, prognostic factors, or concomitant exposures (e.g. smoking). A confounder is a difference between the comparison groups and it influences the direction of the study results. A high quality study at the level of case control design will identify the potential confounders and measure them (where possible). This is difficult for studies where behavioral, attitudinal or lifestyle factors may impact on the results.

7. Were strategies to deal with confounding factors stated?

Strategies to deal with effects of confounding factors may be dealt within the study design or in data analysis. By matching or stratifying sampling of participants, effects of confounding factors can be adjusted for. When dealing with adjustment in data analysis, assess the statistics used in the study. Most will be some form of multivariate regression analysis to account for the confounding factors measured. Look out for a description of statistical methods as regression methods such as logistic regression are usually employed to deal with confounding factors/ variables of interest.

8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?

Read the methods section of the paper. If for e.g. lung cancer is assessed based on existing definitions or diagnostic criteria, then the answer to this question is likely to be yes. If lung cancer is assessed using observer reported, or self-reported scales, the risk of over- or under-reporting is increased, and objectivity is compromised. Importantly, determine if the measurement tools used were validated instruments as this has a significant impact on outcome assessment validity.

Having established the objectivity of the outcome measurement (e.g. lung cancer) instrument, it’s important to establish how the measurement was conducted. Were those involved in collecting data trained or educated in the use of the instrument/s? (e.g. radiographers). If there was more than one data collector, were they similar in terms of level of education, clinical or research experience, or level of responsibility in the piece of research being appraised?

9. Was the exposure period of interest long enough to be meaningful?

It is particularly important in a case control study that the exposure time was sufficient enough to show an association between the exposure and the outcome. It may be that the exposure period may be too short or too long to influence the outcome.

10. Was appropriate statistical analysis used?

As with any consideration of statistical analysis, consideration should be given to whether there was a more appropriate alternate statistical method that could have been used. The methods section should be detailed enough for reviewers to identify which analytical techniques were used (in particular, regression or stratification) and how specific confounders were measured.

For studies utilizing regression analysis, it is useful to identify if the study identified which variables were included and how they related to the outcome. If stratification was the analytical approach used, were the strata of analysis defined by the specified variables? Additionally, it is also important to assess the appropriateness of the analytical strategy in terms of the assumptions associated with the approach as differing methods of analysis are based on differing assumptions about the data and how it will respond.

Appendix 4: Risk of bias assessment for stroke studies

Articles	ITEM1	ITEM 2	ITEM3	ITEM4	ITEM5	ITEM6	ITEM7	ITEM8	ITEM9	ITEM10	Total points	RoB Decision
Amesz et al. 2016	YES	YES	UNC	YES	YES	YES	NO	YES	NA	YES	7	LOW
Boyne et al. 2021	YES	YES	YES	YES	YES	NO	NA	YES	NA	YES	7	LOW
Braun et al. 2017	YES	UNC	YES	YES	YES	NO	NA	YES	NA	YES	6	MODERATE
Daprati et al. 2010	YES	UNC	UNC	YES	YES	UNC	UNC	YES	NA	YES	5	MODERATE
De Bartolo et al. 2020	YES	YES	NO	YES	YES	NO	NA	YES	NA	YES	6	MODERATE
de Vries et al .2013	YES	UNC	UNC	YES	YES	UNC	UNC	YES	NA	YES	5	MODERATE
Demanboro et al. 2018	YES	YES	YES	YES	YES	NO	NA	YES	NA	YES	7	LOW
Dickstein et al. 2005	UNC	UNC	UNC	YES	YES	UNC	UNC	YES	NA	YES	4	MODERATE
Geiger et al. 2017	YES	YES	UNC	YES	YES	YES	NO	YES	NA	YES	7	LOW
Geiger et al. 2018	YES	YES	UNC	YES	YES	YES	NO	YES	NA	YES	7	LOW
Hovington et al. 2010	YES	UNC	UNC	YES	YES	NO	NA	YES	NA	YES	5	MODERATE
Ietswaart et al. 2011	YES	YES	NO	YES	YES	NO	NA	YES	NA	YES	6	MODERATE
Kemlin et al. 2016	YES	UNC	UNC	YES	YES	NO	NA	YES	NA	YES	5	MODERATE
Kimberley et al. 2006	YES	YES	YES	YES	YES	NO	NA	NO	NA	YES	6	MODERATE
Kolbaşı et al. 2020	YES	YES	YES	YES	YES	NO	NA	YES	NA	YES	7	LOW
Lee et al. 2016	YES	UNC	NO	YES	YES	NO	NA	YES	NA	YES	5	MODERATE
Liepert et al. 2016	YES	YES	UNC	YES	YES	NO	NA	YES	NA	YES	6	MODERATE
Liepert et al. 2012	YES	UNC	UNC	YES	YES	UNC	UNC	YES	NA	YES	5	MODERATE
Ma et al. 2022	YES	YES	YES	YES	YES	NO	NA	YES	NA	YES	7	LOW
Malouin et al. 2004	YES	UNC	UNC	YES	YES	NO	NA	YES	NA	YES	5	MODERATE
Malouin et al. 2012	YES	UNC	NO	YES	YES	YES	NO	YES	NA	YES	6	MODERATE
Malouin et al. 2008	YES	UNC	YES	YES	YES	YES	NO	YES	NA	YES	7	LOW
Oostra et al. 2015	YES	UNC	YES	YES	YES	NO	NA	YES	NA	YES	6	MODERATE
Park et al. 2015	YES	UNC	UNC	YES	YES	NO	NA	YES	NA	YES	5	MODERATE
Sapsford 2021	YES	NO	YES	YES	YES	YES	YES	YES	NA	YES	8	LOW
Tanaka et al. 2011	YES	YES	UNC	YES	YES	UNC	UNC	YES	NA	YES	6	MODERATE
Yan et al. 2012	YES	YES	UNC	YES	YES	YES	NO	YES	NA	YES	7	LOW

Appendix 5: Risk of bias assessment for Parkinson’s disease studies

Articles	**ITEM1**	**ITEM 2**	**ITEM3**	**ITEM4**	**ITEM5**	**ITEM6**	**ITEM7**	**ITEM8**	**ITEM9**	**ITEM10**	Total points	Decision
(Avanzino et al. 2013)	**YES**	**YES**	**YES**	**YES**	NO	NO	NA	UNC	NA	**YES**	5	**MODERATE**
(Bek et al. 2019)	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	UNC	**YES**	NA	**YES**	8	**LOW**
(Bek et al. 2022)	UNC	**YES**	**YES**	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	6	**MODERATE**
(Cohen et al. 2011)	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**
(Conson et al. 2014)	**YES**	UNC	UNC	**YES**	**YES**	**YES**	UNC	**YES**	NA	**YES**	6	**MODERATE**
Del Rosario et al. 2023	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**
Esculier et al. 2014	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	NO	NA	**YES**	6	**MODERATE**
Helmich et al. 2012	**YES**	UNC	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	6	**MODERATE**
Heremans et al. 2011	**YES**	UNC	**YES**	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	6	**MODERATE**
Heremans et al. 2012	**YES**	UNC	**YES**	**YES**	**YES**	UNC	UNC	NO	NA	**YES**	5	**MODERATE**
Huang et al. 2021	**YES**	UNC	UNC	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	5	**MODERATE**
Peterson et al. 2012	**YES**	UNC	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	6	**MODERATE**
Scarpina et al. 2019	**YES**	UNC	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	6	**MODERATE**
van Nuenen et al. 2012	**YES**	UNC	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NA	**YES**	7	**LOW**

Appendix 6: Risk of bias assessment for Multiple Sclerosis studies

Articles	ITEM1	ITEM 2	ITEM3	ITEM4	ITEM5	ITEM6	ITEMI7	ITEMI8	ITEMI9	ITEMI10	Total points	Decision
(Allali et al 2012)	**YES**	UNC	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	6	**MODERATE**
(Nogueira et al. 2013)	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**
(Azin et al 2016)	**YES**	UNC	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	6	**MODERATE**
Heremans et al. 2012	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**
Kahraman et al. 2020	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**
Salari et al. 2023	**YES**	**YES**	**YES**	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	7	**LOW**
Tabrizi et al. 2014	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NA	**YES**	9	**LOW**
Tabrizi et al. 2013	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NA	**YES**	8	**LOW**
Tacchino et al. 2013	UNC	UNC	UNC	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	4	**MODERATE**
Tacchino et al. 2018	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**
Wajda et al. 2021	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**

Appendix 7: Risk of bias assessment for Cerebral Palsy studies

Articles	ITEM1	ITEM 2	ITEM3	ITEM4	ITEM5	ITEM6	ITEM7	ITEM8	ITEM9	ITEM10	Total points	Decision
(Crajé et al. 2010)	**YES**	UNC	UNC	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	5	**MODERATE**
Errante et al. 2019	**YES**	UNC	UNC	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	5	**MODERATE**
Galli et al. 2022	**YES**	UNC	UNC	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	5	**MODERATE**
Lust et al. 2016	**YES**	UNC	UNC	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	5	**MODERATE**
Molina et al. 2015	**YES**	UNC	UNC	**YES**	**YES**	UNC	UNC	**YES**	NA	**YES**	5	**MODERATE**
Souto et al. 2020	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NA	**YES**	7	**LOW**

Appendix 8: Risk of bias assessment for Traumatic Brain Injury studies

Articles	ITEM1	ITEM 2	ITEM3	ITEM4	ITEM5	ITEM6	ITEM7	ITEM8	ITEM9	ITEM10	Total points	Decision
Oostra et al. 2012	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NA	**YES**	NA	**YES**	7	**LOW**

Abstract

Introduction: Motor imagery (MI) is a therapeutical option in neurorehabilitation but there is no conclusive evidence about its effectiveness. This could be because MI ability is altered after damage to the central nervous system.

Aim: To investigate whether there is a difference in MI ability between healthy individuals and people with central neurological conditions involving altered motor networks.

Methods: We searched 6 electronic databases up to February 2024. Studies comparing people with stroke, Parkinson's disease (PD), Multiple Sclerosis (MS), Traumatic Brain Injury (TBI) and Cerebral Palsy (CP) with healthy controls (HCs) were included. The selection process and Risk of Bias assessment (by the JBI critical appraisal checklist) was done independently by 2 reviewers. MI ability assessed through questionnaires, mental chronometry, and mental rotation tasks was the outcome extracted. Quantitative and qualitative analyses were used per MI domains and per conditions.

Results: Fifty-nine studies were included. Analysis revealed some evidence for a preserved MI generation ability overall, while mental transformation ability was likely impaired in stroke but preserved in PD and MS. Despite the high heterogeneity in mental timing measures, the trend was toward impairment for this ability.

Conclusion: Compared to HCs, some aspects of MI ability seemed to be preserved in these neurological conditions. The high heterogeneity in mental chronometry measures and the lack of studies for some conditions restricted the summary of evidence.

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