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Research

Motor imagery training improves balance and mobility outcomes in older adults: a systematic review

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KEY WORDS

Rehabilitation
Gait
Motor skills
Postural balance
Aged

ABSTRACT

Question: Does motor imagery training improve measures of balance, mobility and falls in older adults without a neurological condition? **Design**: Systematic review and meta-analysis of randomised controlled trials. **Participants**: Adults aged at least 60 years and without a neurological condition. **Intervention**: Three or more sessions of motor imagery training. **Outcome measures**: The primary outcomes were balance measures (such as single leg stance and Berg Balance scale) and mobility measures (such as gait speed and the Timed Up and Go test). Falls were a secondary outcome measure. Risk of bias was evaluated using the PEDro Scale, and overall quality of evidence was assessed using the Grades of Research, Assessment, Development and Evaluation (GRADE) approach. **Results**: Twelve trials including 356 participants were included in the systematic review and 10 trials (316 participants) were included in the meta-analyses. All trials included either apparently healthy participants or older adults after orthopaedic surgery. There was evidence that motor imagery training can significantly improve balance (SMD 1.03, 95% CI 0.25 to 1.82), gait speed (MD 0.13 m/s, 95% CI 0.04 to 0.22) and Timed Up and Go (MD 1.64 seconds, 95% CI 0.79 to 2.49) in older adults; however, the quality of evidence was very low to low. No data regarding falls were identified. **Conclusion**: Motor imagery training improves balance and mobility in older adults who do not have a neurological condition. These results suggest that motor imagery training could be an adjunct to standard physiotherapy care in older adults, although it is unclear whether or not the effects are clinically worthwhile. **Trial registration**: PROSPERO CRD42017069954. **[Nicholson V, Watts N, Chani Y, Keogh JWL (2019) Motor imagery training improves balance and mobility outcomes in older adults: a systematic review. *Journal of Physiotherapy* 65:200–207]**

Introduction

Age-related deteriorations in balance and mobility contribute to disability, falls and mortality,[1] and place greater strains on the healthcare system. Allied health professionals such as physiotherapists are faced with increased geriatric admission rates[2] and workload pressures[3] to ensure adequate rehabilitation for their older patients via targeted balance, strength and functional training.[4,5] Unfortunately, such training may produce smaller benefits or be unfeasible for certain patient groups, such as those with enforced immobilisation[6] or recently discharged from hospital.[7] Furthermore, even for older adults able to undertake appropriate exercise rehabilitation, there are additional barriers such as poor exercise compliance[8,9] and anxiety relating to unsupervised exercise.[10,11] Importantly, the last decade has seen growth in the use of less physically demanding interventions, such as motor imagery, that may improve a range of functional outcomes in older populations, including balance and mobility,[12,13] while potentially minimising some of the barriers identified with traditional exercise interventions.

Motor imagery is the imagining of an action without its physical execution[14] and motor imagery elicits activity in brain regions that are normally activated during actual task performance.[15] During motor imagery, also known as 'mental practice', the mental imagery of the movement or task to be learned is systematically repeated.[16] The potential benefits of motor imagery as a rehabilitation tool for older adults relies on the ability of motor imagery training to promote motor learning[17] and enhance cortical excitability.[18] The use of motor imagery is particularly appealing for older patient groups that may be unable to undertake traditional exercise training due to weakness, surgical restrictions or immobilisation.[19]

Most motor imagery research has been conducted in patients with neurological conditions, as is evident in systematic reviews of trials in stroke[12,20] and Parkinson's disease.[13] These reviews have helped to inform training recommendations for these groups.[12,13,20] Within these reviews, motor imagery has been shown to promote motor planning[20] and improve upper limb function,[12,20] mobility[12] and balance.[12] Furthermore, motor imagery has recently been shown to be more effective when used in conjunction with action observation

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Box 1. Inclusion criteria.

Design
- Randomised controlled trials

Participants
- Adults with a mean age of at least 60 years and without a neurological condition

Intervention
- A motor imagery intervention (with or without an action observation intervention) performed on at least three occasions
- Sufficient reporting of dose (eg, time per session, sessions completed, weeks of training)

Outcome measures
- At least one objective measure of mobility or balance at baseline and follow-up

Comparisons
- Motor imagery versus either no intervention or placebo/sham intervention
- Motor imagery plus additional intervention (eg, usual care) versus the additional intervention only (eg, usual care only)

for balance activities.[21] Action observation, like motor imagery, is a motor simulation technique[22] that involves an individual watching motor actions performed by someone else, leading to the activation of the same neural structures responsible for the execution of those same actions.[23]

To date, no systematic review has assessed the impact of motor imagery training on balance and mobility in non-neurological older adult participants. Inspection of the literature reveals that a wide variety of motor imagery intervention protocols have been utilised for older adults, with differences in training duration, imagery type, frequency of exposure, and tasks trained, as well as outcome measures identified. There are also many examples of methodological concerns among these studies[24,25] and conflicting findings regarding the effects of motor imagery training on balance and mobility in older adults.[25,26] These issues within the motor imagery literature make it difficult to observe the overall effectiveness of motor imagery for improving balance and mobility in older adults.

Therefore, the research question for this systematic review and meta-analysis is:

> Does motor imagery training improve measures of balance, mobility and falls in older adults without a neurological condition?

Method

This systematic review adhered to the statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions (PRISMA)[27] and was prospectively registered.

Identification and selection of studies

A comprehensive search of five electronic databases (Medline, EMBASE, CINAHL, Physiotherapy Evidence Database (PEDro), and PsychINFO) was performed from the earliest records to January 2019. The search strategy was based around synonyms and subject headings of the key concepts of *motor imagery* and *older adults* combined with the primary outcomes relating to *balance* and *mobility*. The detailed search strategy for each database is presented in Appendix 1 (see eAddenda for Appendix 1). The database searches were supplemented by reference checks of the included articles. Studies published in English and French were included; those in any other language were noted but excluded from analyses.

Trials assessing the effectiveness of motor imagery on balance and mobility outcomes were included if they met the inclusion criteria listed in Box 1. Furthermore, the detail of motor imagery training dosage (time per session, weeks of training) and information relating to the activities trained needed to be reported. A two-stage screening process was used to select relevant trials for this review. In the first stage, two reviewers (NW and YC) independently considered information from the titles and abstracts and excluded clearly irrelevant studies. In the second stage, the full text for each potentially eligible study was retrieved and assessed against the eligibility criteria by two independent reviewers (NW and YC). Disagreements were resolved by discussion with a third reviewer (VN or JK).

Assessment of characteristics of studies

Study quality

Study quality was assessed using the PEDro Scale by downloading the available scores from the PEDro database. If a study had not been rated on the PEDro database, it was assessed independently by two authors (NW and YC).[28] The total score on the PEDro Scale is the addition of 'yes' (criterion is clearly satisfied) responses for Items 2 to 11 (Item 1 is not used for calculation of the total PEDro Scale as it relates to external validity). The 10 criteria contribute 1 point each, thereby providing a score range of 0 to 10. A PEDro score of $\geq$ 6 out of 10 was considered to represent high quality.[29] The PEDro score is a valid measure of methodological quality and completeness of reporting, and has moderate levels of inter-rater reliability.[30,31]

Participants

Trials were included if the mean age of the trial participants was at least 60 years. Studies that included participants who were regarded as apparently healthy or were recovering from elective orthopaedic surgery were eligible. Studies that included participants with a neurological condition such as stroke or Parkinson's disease were ineligible.

Intervention

To be eligible for inclusion, trials had to evaluate a motor imagery training intervention targeting balance or mobility. The intervention had to include multiple motor imagery training sessions. Trials were included if they used motor imagery as an intervention in isolation or if motor imagery was used as an intervention in addition to standard care. Motor imagery interventions that included the combination of motor imagery and action observation (observing a video or demonstration of an activity) were also included.

Outcomes measures

To be eligible for inclusion, trials had to report on a post-intervention objective outcome measure of balance or mobility. For this review, balance outcomes included static (eg, single leg stance) and dynamic measures of balance (eg, four step square test) as well as tasks that required participants to walk with a narrow base of support (eg, tandem type walking) or stepping on pre-determined targets (eg, obstacle course). Mobility outcomes were limited to tasks that primarily involved normal straight-line walking with no restraint on stance width or obstacle avoidance, such as the timed 10-m walk test or the Timed Up and Go test (TUG). The incidence of falls was also included as a secondary outcome measure.

Comparison

The contrast between the randomised interventions was required to be motor imagery versus no intervention or sham intervention. Studies with co-interventions were included provided the co-intervention was delivered to both groups (eg, motor imagery plus usual care versus usual care).

Data analysis

A customised data extraction table was applied to each eligible trial by one of two study authors (NW or YC) and extracted data were checked for accuracy and completeness by a senior author (VN or JK). The extracted data included information regarding study design, participants (age, gender), intervention (type of imagery, frequency of

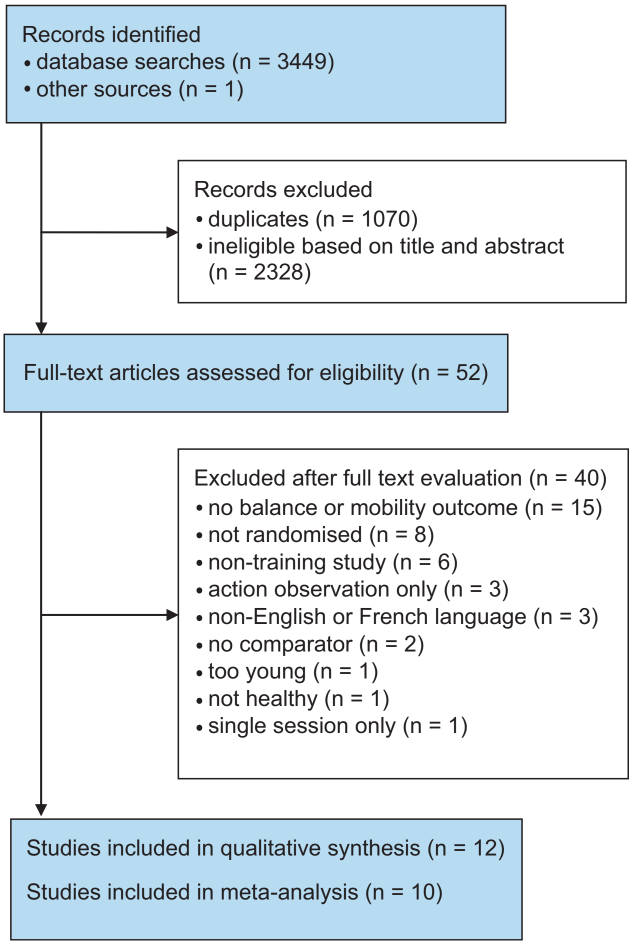

Figure 1. Flow of studies through the review.

sessions, setting, supervision), comparison group characteristics (standard care, sham imagery, no training), outcome measures and main findings.

Means and standard deviations for post-intervention outcomes (all continuous variables) were entered in Review Manager (RevMan)[32] software, version 5.3. Some outcome measures for mobility and balance function indicate improvement by increases in values (eg, gait speed) while others indicate improvement by decreases in values (eg, TUG time). To adjust for the different outcome directions, for those outcomes that report improvement with decreasing values, the values were transformed by multiplying the values by -1. Raw data (means and SD) of post-intervention data were extracted from each paper. Authors were contacted if there were insufficient published data for analysis.

Balance and mobility measures were analysed separately because, although mobility requires inherent dynamic balance,[33] these outcomes may assess different aspects of function relevant to the older adult. For this review, balance outcomes included static and dynamic measures of balance as well as tasks that required participants to walk with a narrow base of support or stepping on pre-determined targets. Mobility was defined as the ability to move independently from one point to another[34] and included tasks that primarily involved normal straight-line walking or stair climbing (eg, timed 10-m walk test, TUG, stair climb test) as these assessments are widely used to quantify mobility capabilities in older adults.[35]

For balance, due to differences in outcomes assessed and measurement scales used between studies, the standardised mean difference (SMD) with 95% CI was calculated for each study and then pooled to compare the control and intervention groups. For mobility measures, gait speed and TUG were assessed across multiple studies; therefore, mean differences (MD) with 95% CI were calculated for gait speed and TUG, so a clinically meaningful unit (eg, gait speed in m/s or time to complete the TUG in seconds) could be presented.

Meta-analysis was completed using RevMan[32] version 5.3 to provide evidence of the pooled effect size of the motor imagery interventions. Heterogeneity was tested with chi-square measured by inspection of the I^2 values that described the percentage of the variability in effect estimates that was due to heterogeneity rather than sampling error. A fixed-effect model was used if the I^2 value was $\leq$ 50% and a random-effects model was used if the I^2 value was $>$ 50%. Additionally, where substantial ($>$ 50%) heterogeneity was observed,[36] sensitivity analyses were conducted to check whether the heterogeneity was caused by a single study. In this case, the leave-one-out approach was performed by removing the outlying study.

The overall quality of evidence was assessed for each intervention contrast and rated as high, moderate, low, or very low, as recommended by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system.[37] The GRADE classification was downgraded one level per study flaw, from high quality, if any of the following flaws were present: design limitation (if the majority of studies in the meta-analysis had a PEDro score $<$ 6); inconsistency of results (substantial heterogeneity, $I^2 >$ 50%) and imprecision based on small samples ($<$ 400 for each pooled outcome). This review did not consider the indirectness criterion because the eligibility criteria ensured a specific population with relevant outcomes. In addition, the review did not assess publication bias due to insufficient study numbers (ie, $<$ 10 studies per meta-analysis).

Sensitivity analyses

Sensitivity analyses were conducted to examine the robustness of the primary meta-analyses for balance and mobility measures. The sensitivity analyses explored the effect of including only high-quality (PEDro $\geq$ 6) studies in the analysis, to account for methodological aspects that may bias the overall result.

Results

Flow of studies through the review

The electronic database search resulted in a yield of 3449 articles, which was reduced to 2380 after duplicates were removed. Following title and abstract screening, 52 articles were obtained in full text and further assessment reduced the yield to 12 articles that were included in the systematic review (Figure 1). Ten studies were included in the meta-analysis, with two studies not included in the meta-analysis due to insufficient post-intervention data.[25,38]

Characteristics of studies

Quality

The mean score of the included trials was 4.8 (SD 1.6) on the PEDro Scale. Four[39–42] of the 12 included studies were regarded as high-quality studies as they had PEDro scores of $\geq$ 6. Blinding, concealed allocation and intention-to-treat analysis were the main items susceptible to bias amongst the included studies. The PEDro Scale responses for individual items and the total score for each included randomised controlled trial are presented in Table 1.

Participants

The 12 included studies were conducted between 1985 and 2018, and involved 356 participants (Table 2). The mean age of participants among the included studies ranged from 64 to 79 years. The majority of participants were female (66%). Eight studies[24–26,38,42–45] assessed apparently healthy older adults, three studies[39,40,46] assessed older adults following non-traumatic orthopaedic surgery (knee or hip arthroplasty), and one study assessed apparently healthy older adults with a fear of falling.[41]

Intervention

All trials included at least three sessions of motor imagery training (Table 2). Motor imagery training was undertaken in the home in four trials,[25,41,42,45] in a clinic or laboratory setting in four trials,[24,38,43,44] in a hospital then at home in three trials,[39,40,46] and in a library for one

Table 1
PEDro criteria and scores for included trials (n = 12).

Study	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	< 15% dropouts	Intention -to-treat analysis	Between-group difference reported	Point estimate and variability reported	Total (0 to 10)
Batson[26]	Y	N	N	N	N	N	Y	Y	N	N	3
Chiacchiero[38]	Y	N	Y	N	N	Y	N	N	Y	Y	5
Fansler[24]	Y	N	N	N	Y	Y	N	N	Y	Y	5
Goudarzian[43]	Y	N	Y	N	N	N	Y	N	Y	Y	5
Hamel and Lajoie[25]	Y	N	N	N	N	N	N	N	Y	N	2
Jacobson[39]	Y	Y	Y	N	Y	Y	N	N	Y	Y	7
Kim[41]	Y	N	Y	Y	N	N	Y	N	Y	Y	6
Linden[42]	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Marusic[46]	Y	N	Y	N	N	N	N	N	Y	Y	4
Moshref-Razavi[44]	Y	N	N	N	N	N	N	N	Y	Y	3
Moukarzel[40]	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Tunney[45]	Y	N	N	N	N	N	Y	N	Y	Y	4

N = no, PEDro = Physiotherapy Evidence Database, Y = yes.

trial.[26] Motor imagery was delivered via audio guidance in six studies,[25,26,38,39,41,42] where participants listened to pre-recorded instructions. Four studies[24,40,43,44] used trainer-guided motor imagery, which involved a trainer (eg, a physiotherapist) reading a motor imagery script in real time to guide participants' imagery practice. One study used independent motor imagery that was preceded by initial training and written instructions,[45] and one study used video-guided motor imagery (combined action observation with motor imagery).[46] Motor imagery interventions ranged from three sessions conducted over consecutive days[24] to seven sessions per week for 6 weeks.[25] Three studies prescribed three sessions per week for 8 weeks.[43,44,46] The duration of motor imagery sessions ranged from < 30 seconds[45] to 30 minutes[25,46] including rest breaks. The total time spent performing motor imagery training over the course of the interventions ranged from 2 minutes[45] to 21 hours.[25] The tasks trained during the motor imagery interventions included static standing,[24,25,38,44] rising from a chair,[26] mobility tasks such as the TUG,[43] walking,[39,41,46] stairs[39,45,46] and obstacle course.[42] The tasks trained in all but one study[40] included tasks that closely matched an outcome measure of balance or mobility assessed after the intervention. In the other study, participants were instructed to imagine muscle contractions and knee joint movements following knee joint surgery.[40]

Adherence

Adherence to motor imagery was poorly reported and was only explicitly measured in one study. In that 5-week program, 90% of participants reported listenening to the imagery tracks as prescrbed during the preoperative and postoperative periods.[39]

Effects of motor imagery on balance and mobility outcomes

Balance

Meta-analysis of six studies with a total of 114 participants provided very low-quality evidence that motor imagery had a positive effect on balance when compared with controls (SMD 1.03, 95% CI 0.25 to 1.82, I^2 = 67%) (Figure 2, see also Figure 3 on the eAddenda for a detailed forest plot). The evidence was downgraded from high quality to very low quality due to design limitations (five of six trials had PEDro of < 6), imprecision (sample size < 400) and substantial heterogeneity (I^2 = 67%) (Table 3). Due to substantial heterogeneity (I^2 > 50%), a sensitivity analysis was performed, which revealed that the pooled estimate was most influenced by one study.[26] When this study was removed, heterogeneity remained substantial (I^2 = 58%). When this outlying study was omitted, the pooled result remained significant (SMD 1.18, 95% CI 0.52 to 1.85, I^2 = 58%) in favour of motor imagery training.

Mobility

The influence of motor imagery on mobility was assessed with separate meta-analyses for gait speed and TUG, to allow for presentation of results as mean difference in their respective units.

Meta-analysis of three studies with a total of 107 participants provided low-quality evidence that motor imagery had a positive effect on gait speed when compared with controls (MD 0.13 m/s, 95% CI 0.04 to 0.22, I^2 = 0%) (Figure 4, see also Figure 5 on the eAddenda for a detailed forest plot). The evidence was low quality due to design limitations (two of three trials had PEDro of < 6) and imprecision (sample size < 400).

Meta-analysis of six studies with a total of 175 participants provided low-quality evidence that motor imagery had a positive effect on time to complete the TUG when compared with controls (MD 1.64 seconds, 95% CI 0.79 to 2.49, I^2 = 0%) (Figure 6, see also Figure 7 on the eAddenda for a detailed forest plot). The evidence was low quality due to design limitations (four of six trials had PEDro of < 6) and imprecision (sample size < 400).

Falls

None of the eligible studies reported data on falls incidence.

Sensitivity analyses

A sensitivity analysis could only be conducted for the TUG, as there was only one high-quality study within the overall meta-analysis for both balance and gait speed. When only high-quality trials (PEDro score ≥ 6) were included in the meta-analysis for the TUG (n = 2, total of 111 participants), motor imagery still had a positive effect on time to complete TUG compared with controls (MD 1.67 seconds, 95% CI 0.50 to 2.83, I^2 = 0%) (Figure 8, see also Figure 9 on the eAddenda for a detailed forest plot).

Discussion

This systematic review provides evidence that motor imagery can improve measures of balance and mobility, such as gait speed, in neurologically normal older adults. These findings partly align with a recent systematic review and meta-analysis of data from stroke patients, which also identified improvements in balance and mobility outcomes following motor imagery training.[12] Encouragingly, the meta-analyses for gait speed and TUG had mean differences that would be considered clinically worthwhile. The mean difference of 0.13 m/s for gait speed exceeds the estimated level of substantial change (0.1 m/s) for older adults[47,48] and aligns with the minimal detectable change identified for short-term rehabilitation in older adults.[49]

Table 2
Characteristics of the included trials.

Study	Participants [a]	Motor imagery intervention description; setting	Target movement/activity trained during MI	Comparator/control group description; setting	Outcome measure	
					Mobility	Balance
Batson (2007)[26]	N = 6 apparently healthy Age (*yr*) = 65 to 80 Gender = 6 F	20 min of physical practice (eg, sit to stand) + 20 min audiotape-guided MI with visual and kinaesthetic cueing, 2/wk for 6 wks; library	Functional tasks such as rising from a chair and body scanning	20 min physical practice (eg, sit to stand) + 20 min educational control (eg, falls prevention, footwear) 2/wk for 6 wks; library	TUG *(s)*	BBS *(0 to 56)*
Chiacchiero (2015)[38 b]	N= 20 apparently healthy Age (*yr*) = 79 Gender = 3 M, 17 F	Audiotape-guided MI: 20 min MI, 3/wk for 4 wks; clinic	Standing and reaching tasks	Control group instructed not to actively listen to tape, 3/wk for 4 wks; clinic		FRT forward, left, right *(cm)* Body sway: length *(cm)* and velocity *(cm/s)*
Fansler (1985)[24]	N = 30 apparently healthy Age (*yr*) = 78 Gender = 30 F	Trainer-guided MI: 10 min consisting of graded relaxation and MI over 3 d; clinic	Single leg balance	Physical one leg balance + 10 min progressive relaxation (as per start of intervention group) over 3 d; clinic		Single leg stance *(s)*
Goudarzian (2017)[43]	N = 24 apparently healthy Age (*yr*) = 68 Gender = 24 M	Trainer-guided: 10 min relaxation then 5 to 8 mins MI, 3 d/wk for 8 wks; laboratory	TUG	Nil training, continue with normal daily routine	TUG *(s)* 10MWT *(s)*	6-m tandem Gait *(s)*
Hamel and Lajoie (2005)[25 b]	N = 20 apparently healthy Age range (*yr*) = 65 to 90 Gender = 6 M, 14 F	Audiotape-guided: 5 min relaxation followed by 30 kinaesthetic MI, 7/wk for 6 wks; home	Static standing on a platform	Nil training, continue with normal daily routine		Body sway (anteroposterior and lateral)
Jacobson (2016)[39]	N = 58 post-orthopaedic surgery Age (*yr*) = 65 (8) Gender = NR	Audiotape-guided MI with background relaxation music; 20 mins, 7/wk for 5 wks (2 wks preop, 3 wks postop); hospital and home	Activities to facilitate mind-body connections to promote confidence in operated knee, plus guided imagery related to standing posture, walking and stairs	20 min commercially available audio recordings (poetry, short stories); 7 x/wk for 5 wks (2 wks preop, 3 wks postop); hospital and home	10MWT *(s)*	
Kim (2012)[41]	N = 91 apparently healthy, with FoF Age (*yr*) = 76 Gender = 35 M, 56 F	Audiotape-guided relaxation and MI: 10 to 15 mins, 2/wk for 6 weeks; home	Guided relaxation and progressively challenging locomotor tasks such as walking in the house and on an icy road	Audiotape-guided relaxation and music: 10 to 15 mins, 2/wk for 6 wks; home	TUG *(s)*	
Linden (1989)[42]	N = 23 apparently healthy Age (*yr*) = 67 to 90 Gender = 23 F	Audiotape-guided: 6 mins daily for 8 d to assist with imagining walking up a ramp, balance beam and step off; home	Obstacle course	Memory games; 6 mins daily for 8 d; home		Obstacle course with narrow gait and balance reactions *(0 to 20)*
Marusic (2018)[46]	N = 21 post-orthopaedic surgery Age (*yr*) = 64 Gender = 14 M, 7 F	Standard physical rehabilitation + video-guided (action observation) followed by MI: 30 mins, 3/wk for 8 wks; hospital and home	Locomotor tasks such as normal walking, stair climbing, walking on narrow surfaces	Standard physical rehabilitation plus watching documentary videos; 3/wk for 8 wks; hospital and home	TUG *(s)* Gait speed *(m/s)*	Four Step Square Test *(s)*
Moshref-Razavi (2017)[44]	N = 24 apparently healthy Age (*yr*) = 60 to 82 Gender = NR	Trainer-guided: 10 min relaxation, 15 min MI, 3/wk for 8 wks; laboratory	Single leg balance	Nil training, continue with normal daily routine	TUG *(s)*	
Moukarzel (2017)[40]	N = 20 post-orthopaedic surgery Age (*yr*) = 69 Gender = 4 M, 16 F	60 min physical rehabilitation (passive ROM, quads strength, gait re-ed) + 15 min trainer-guided MI; 3/wk for 4 wks; hospital and home	Muscle contractions and knee joint movement	60 min physical rehabilitation (passive ROM, quads strength, gait re-ed), 3/wk for 4 wks; hospital and home	TUG *(s)*	
Tunney (2006)[45]	N = 19 apparently healthy Age (*yr*) = 76 Gender = 6 M, 13 F	Participant derived with a live demonstration and scripted verbal instruction: 4 sessions over 48 hours; home	Ascending/descending stairs with a 4-point stick	Nil training, continue with normal daily routine	Stair climbing *(0 to 20)*	

BBS = Berg Balance Scale, F = female, FoF = fear of falling, FRT = Functional reach test, M = male, MI = motor imagery, NR = not reported, TUG = Timed Up and Go test, 10MWT = 10-m walk test, re-ed = re-education, ROM = range of motion.
[a] Age is presented as mean, mean (SD), or range.
[b] Not included in meta-analysis due to lack of post-intervention data.

Similarly, the mean difference of 1.64 seconds for TUG exceeds the minimum clinically important difference of approximately 1.3 seconds identified for patients with lower limb osteoarthritis.[50,51] However, the confidence interval around each of these estimates does extend below the nominated threshold; therefore, it must be acknowledged that the effects may or may not be clinically worthwhile.

It is more challenging to identify the clinical significance of improvements seen for balance, because although an SMD of 1.03 indicates a moderate-to-large effect size, multiple balance outcomes were assessed, a substantial degree of heterogeneity was identified, and large 95% CIs were present in the meta-analysis.

While one of the strengths of this systematic review and meta-analysis was that it included only randomised controlled trials, a

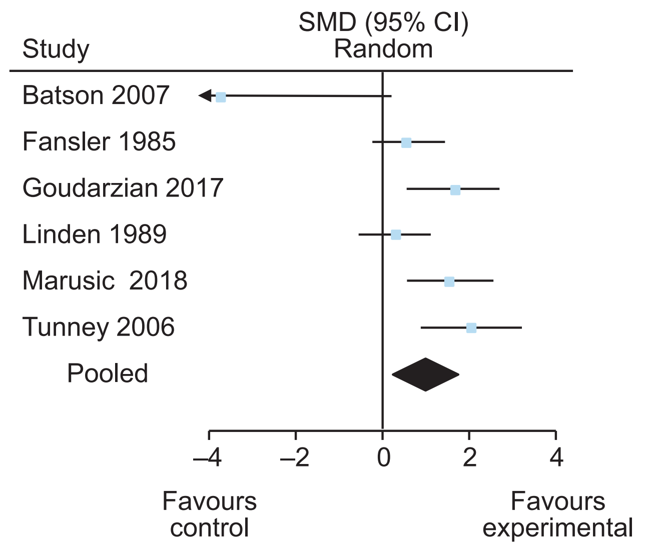

Figure 2. Standardised mean difference (95% CI) in the effect of motor imagery training versus no intervention or sham on balance measures.

limited number of high-quality studies were included in the meta-analysis. This is highlighted by the GRADE quality ratings of low and very low assigned to the outcomes of the meta-analyses. Such ratings suggest that the true effect may be markedly different from the estimated effect.[37] Downgrading of quality was largely based on design limitations (predominantly low-quality studies: PEDro < 6) and low sample sizes. The low PEDro scores were primarily related to issues with allocation concealment, blinding of assessors and intention-to-treat analysis. Another limitation was that post-intervention data were used instead of change data. Change data may have provided a more precise estimate of effect of motor imagery training on balance and mobility but change data was not consistently presented across all studies. Post-intervention data were used in preference to change data because these were the most commonly provided data in studies. Despite these limitations, it is important to note that the positive results associated with motor imagery training still existed for TUG when only high-quality studies were included in the meta-analysis. Such a result is in contrast to a previous review of stroke patients, where the benefits in lower limb function and gait speed were no longer evident when only high-quality studies were included in analyses.[12] The effect of assessing only high quality studies for balance and gait speed was not possible, as each meta-analysis included just one high quality study.

Clearly, further motor imagery research that incorporates appropriate research design characteristics including blinded assessors, concealed allocation and larger sample sizes will help to provide more robust evidence in this area. Future studies should also focus on patient groups that are less able to undertake traditional rehabilitation, such as those with enforced immobilisation or restricted weight-bearing, as they may most benefit from motor imagery training.

Table 3
Grades of Recommendation, Assessment, Development and Evaluation (GRADE) quality of evidence.

Outcome	Trials (n)	Participants	SMD or MD (95% CI), I^2	Quality of Evidence (GRADE)
Balance	6	114	SMD 1.03 (0.25, 1.82), 67%	Very low [a]
Gait speed (m/s)	3	107	MD 0.13 (0.04, 0.22), 0%	Low [b]
TUG (s)	6	175	MD 1.64 (0.79, 2.49), 0%	Low [c]

MD = mean difference, SMD = standardised mean difference, TUG = Timed Up and Go test.
[a] Downgraded due to design limitations (five of six trials had PEDro of < 6), imprecision (low sample size) and substantial heterogeneity.
[b] Downgraded due to design limitations (two of three trials had PEDro of < 6), imprecision (low sample size).
[c] Downgraded due to design limitations (four of six trials had PEDro of < 6) and imprecision (low sample size).

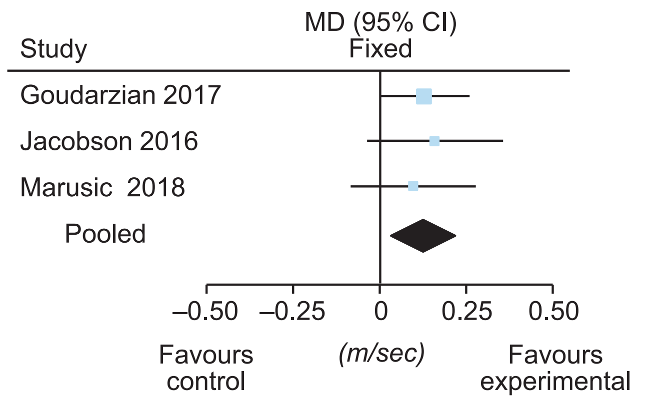

Figure 4. Mean difference (95% CI) in the effect of motor imagery training versus no intervention or sham on gait speed.

Further information regarding program compliance and participant perceptions of motor imagery and action observation should also be included in future studies.

Another strength of this systematic review was that all but three studies[24,42,45] prescribed a motor imagery training intervention of at least 4 weeks, which appears to be a sufficient duration to promote gains in performance.[52] Although not established for balance or mobility measures, a recent meta-analysis identified that a training period of 4 weeks, involving a training frequency of three times per week and a session duration of 15 minutes, was associated with enhanced strength improvements following motor imagery training.[52] Furthermore, most motor imagery training studies in the present review were conducted in a group setting or were self-directed with the aid of audiotape guidance. This has clinical relevance, as the use of effective training programs in group settings or unsupervised environments reduces therapist burden,[3] reduces 'wasted' time outside of structured therapy[53] and typically represents low-cost interventions,[54] suggesting that the inclusion of motor imagery training in rehabilitation programs for older adults is very feasible.

The improvements in mobility associated with motor imagery training identified in this systematic review are thought to be largely explained by improvements in motor planning that promote motor learning.[19,55] Motor learning associated with motor imagery training has long been established in sport,[56] in rehabilitation settings,[57,58] and more recently in older adults.[59] Motor imagery elicits activity in brain regions that are normally activated during actual task performance[60,61] and the spatiotemporal characteristics of imagined and

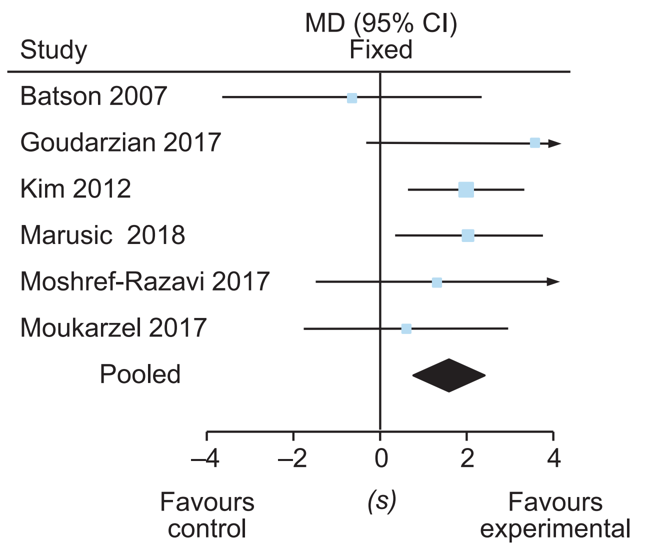

Figure 6. Mean difference (95% CI) in the effect of motor imagery training versus no intervention or sham on time to complete the Timed Up and Go test.

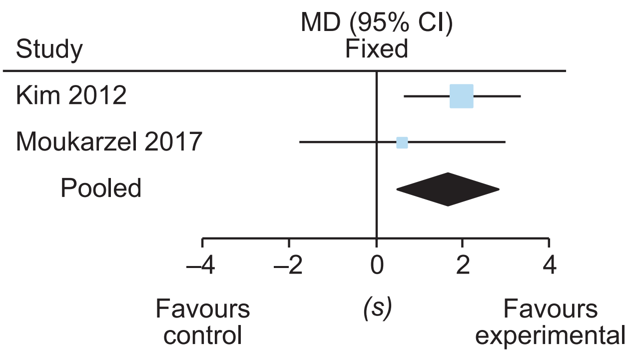

Figure 8. Mean difference (95% CI) in the effect of motor imagery training versus no intervention or sham on time to complete the Timed Up and Go test (high quality studies only).

physical movements are closely matched for mobility tasks.[62,63] Improvements in motor task execution (such as increased gait speed) following motor imagery training are believed to be due to the development and refining of the internal representation of the motor task via activation of the movement-related neural network.[61] The refinement of these internal motor representations makes motor imagery training an attractive option for patient groups that require motor task enhancement but are unable to complete traditional physical training interventions due to illness, surgical restrictions or enforced immobilisation.

In conclusion, the present systematic review and meta-analysis showed that motor imagery training improves measures of balance and mobility in older adults that do not have neurological conditions. Specifically, when motor imagery is used in isolation or in combination with established physical rehabilitation, it can promote improvements in mobility that may exceed established values for clinically meaningful change for older adults.

What was already known on this topic: Targeted balance, strength and functional training is effective in older people. Such training can be impaired or precluded in some older people, such as those with prescribed mobility restrictions after recent surgery, or with anxiety about exercising without supervision. Motor imagery training involves repetitive mental rehearsal of an action without executing that action physically.
What this study adds: In older people, multiple sessions of mental imagery training clearly improve measures of balance and mobility. Due to limitations in the amount and quality of the available data, it is not yet possible to confirm whether these benefits are large enough to be considered worthwhile.

eAddenda: Figures 3, 5, 7 and 9 and Appendix 1 can be found online at https://doi.org/10.1016/j.jphys.2019.08.007.

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References

1. Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, et al. Gait speed and survival in older adults. *JAMA*. 2011;305:50–58.
2. AIHW. *Admitted patient care 2016–17: Australian hospital statistics*. Canberra: Australian Institute of Health and Welfare; 2018.
3. Scurlock-Evans L, Upton P, Upton D. Evidence-based practice in physiotherapy: a systematic review of barriers, enablers and interventions. *Physiotherapy*. 2014;100:208–219.
4. Lesinski M, Hortobágyi T, Muehlbauer T, Gollhofer A, Granacher U. Effects of balance training on balance performance in healthy older adults: a systematic review and meta-analysis. *Sports Med*. 2015;45:1721–1738.
5. Sherrington C, Michaleff ZA, Fairhall N, Paul SS, Tiedemann A, Whitney J, et al. Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. *Br J Sports Med*. 2017;51:1750–1758.
6. Gauthé R, Desseaux A, Rony L, Tarissi N, Dujardin F. Ankle fractures in the elderly: treatment and results in 477 patients. *Orthop Traumatol Surg Res*. 2016;102:S241–S244.
7. Naseri C, Haines TP, Etherton-Beer C, McPhail S, Morris ME, Flicker L, et al. Reducing falls in older adults recently discharged from hospital: a systematic review and meta-analysis. *Age Ageing*. 2018;47:512–519.
8. Haines TP, Russell T, Brauer SG, Erwin S, Lane P, Urry S, et al. Effectiveness of a video-based exercise programme to reduce falls and improve health-related quality of life among older adults discharged from hospital: a pilot randomized controlled trial. *Clin Rehabil*. 2009;23:973–985.
9. Fairhall N, Sherrington C, Cameron ID, Kurrle SE, Lord SR, Lockwood K, et al. A multifactorial intervention for frail older people is more than twice as effective among those who are compliant: complier average causal effect analysis of a randomised trial. *J Physiother*. 2017;63:40–44.
10. Courtney M, Edwards H, Chang A, Parker A, Finlayson K, Hamilton K. Fewer emergency readmissions and better quality of life for older adults at risk of hospital readmission: a randomized controlled trial to determine the effectiveness of a 24-week exercise and telephone follow-up program. *J Am Geriatr Soc*. 2009;57:395–402.
11. Burton E, Farrier K, Lewin G, Pettigrew S, Hill AM, Airey P, et al. Motivators and barriers for older people participating in resistance training: a systematic review. *J Aging Phys Act*. 2017;25:311–324.
12. Guerra ZF, Lucchetti ALG, Lucchetti G. Motor imagery training after stroke: a systematic review and meta-analysis of randomized controlled trials. *J Neurol Phys Ther*. 2017;41:205–214.
13. Caligiore D, Mustile M, Spalletta G, Baldassarre G. Action observation and motor imagery for rehabilitation in Parkinson's disease: a systematic review and an integrative hypothesis. *Neurosci Biobehav Rev*. 2017;72:210–222.
14. Jeannerod M, Decety J. Mental motor imagery: a window into the representational stages of action. *Curr Opin Neurobiol*. 1995;5:727–732.
15. Hétu S, Grégoire M, Saimpont A, Coll MP, Eugène F, Michon PE, et al. The neural network of motor imagery: an ALE meta-analysis. *Neurosci Biobehav Rev*. 2013;37:930–949.
16. Jackson PL, Lafleur MF, Malouin F, Richards CL, Doyon J. Potential role of mental practice using motor imagery in neurologic rehabilitation. *Arch Phys Med Rehabil*. 2001;82:1133–1141.
17. Di Rienzo F, Debarnot U, Daligault S, Saruco E, Delpuech C, Doyon J, et al. Online and offline performance gains following motor imagery practice: A comprehensive review of behavioral and neuroimaging studies. *Front Hum Neurosci*. 2016;10:315.
18. Clark BC, Mahato NK, Nakazawa M, Law TD, Thomas JS. The power of the mind: the cortex as a critical determinant of muscle strength/weakness. *J Neurophysiol*. 2014;112:3219–3226.
19. Taube W, Lorch M, Zeiter S, Keller M. Non-physical practice improves task performance in an unstable, perturbed environment: motor imagery and observational balance training. *Front Hum Neurosci*. 2014;8:972.
20. Braun S, Kleynen M, van Heel T, Kruithof N, Wade D, Beurskens A. The effects of mental practice in neurological rehabilitation: a systematic review and meta-analysis. *Front Hum Neurosci*. 2013;7:390.
21. Taube W, Mouthon M, Leukel C, Hoogewoud H, Annoni J, Keller M. Brain activity during observation and motor imagery of different balance tasks: an fMRI study. *Cortex*. 2015;64:102–114.
22. Vogt S, Di Rienzo F, Collet C, Collins A, Guillot A. Multiple roles of motor imagery during action observation. *Front Hum Neurosci*. 2013;7:807.
23. Fabbri-Destro M, Rizzolatti G. Mirror neurons and mirror systems in monkeys and humans. *J Physiol*. 2008;23:171–179.
24. Fansler CL, Poff CL, Shepard KF. Effects of mental practice on balance in elderly women. *Phys Ther*. 1985;65:1332–1338.
25. Hamel MF, Lajoie Y. Mental imagery. Effects on static balance and attentional demands of the elderly. *Aging Clin Exp Res*. 2005;17:223–228.
26. Batson G, Feltman R, McBride C, Waring J. Effect of mental practice combined with physical practice on balance in the community-dwelling elderly. *Act Adaptation Aging*. 2007;31:1–18.
27. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6:e1000097.
28. Elkins MR, Herbert RD, Moseley AM, Sherrington C, Maher CJ. Rating the quality of trials in systematic reviews of physical therapy interventions. *Cardiopulm Phys Ther J*. 2010;21:20.
29. Hahne AJ, Ford JJ, McMeeken JM. Conservative management of lumbar disc herniation with associated radiculopathy: a systematic review. *Spine*. 2010;35:E488–E504.
30. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther*. 2003;83:713–721.
31. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother*. 2009;55:129–133.
32. *Review Manager (RevMan)* [computer program]. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration; 2014.
33. Woollacott MH, Pei-Fang T. Balance control during walking in the older adult: research and its implications. *Phys Ther*. 1997;77:646.
34. Patla AE, Shumway-Cook A. Dimensions of mobility: defining the complexity and difficulty associated with community mobility. *J Aging Phys Act*. 1999;7:7–19.

35. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N Engl J Med*. 1995;332:556–562.
36. Higgins JPT, Green SE. *Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0 [updated March 2011]*. The Cochrane Collaboration; 2011.
37. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ*. 2008;336:924–926.
38. Chiacchiero M, Cagliostro P, DeGenaro J, Giannina C, Rabinovich Y. Motor imagery improves balance in older adults. *Top Geriatr Rehabil*. 2015;31:159–163.
39. Jacobson AF, Umberger WA, Palmieri PA, Alexander TS, Myerscough RP, Draucker CB, et al. Guided imagery for total knee replacement: a randomized, placebo-controlled pilot study. *J Altern Complement Med*. 2016;22:563–575.
40. Moukarzel M, Di Rienzo F, Lahoud J, Hoyek F, Collet C, Guillot A, et al. The therapeutic role of motor imagery during the acute phase after total knee arthroplasty: a pilot study. *Disabil Rehabil*. 2017:1–8.
41. Kim BH, Newton RA, Sachs ML, Glutting JJ, Glanz K. Effect of guided relaxation and imagery on falls self-efficacy: a randomized controlled trial. *J Am Geriatr Soc*. 2012;60:1109–1114.
42. Linden CA, Uhley JE, Smith D, Bush MA. The effects of mental practice on walking balance in an elderly population. *Occup Ther J Res*. 1989;9:155–169.
43. Goudarzian M, Ghavi S, Shariat A, Shirvani H, Rahimi M. Effects of whole body vibration training and mental training on mobility, neuromuscular performance, and muscle strength in older men. *J Exerc Rehabil*. 2017;13:573.
44. Moshref-Razavi S, Sohrabi M, Sotoodeh MS. Effect of neurofeedback interactions and mental imagery on the elderly's balance. *Iran J Ageing*. 2017;12:288–299.
45. Tunney N, Billings K, Blakely BG, Burch D, Hill M, Jackson K. Mental practice and motor learning of a functional motor task in older adults: a pilot study. *Phys Occup Ther Geriatr*. 2006;24:63–80.
46. Marusic U, Grosprêtre S, Paravlic A, Kovač S, Pišot R, Taube W. Motor imagery during action observation of locomotor tasks improves rehabilitation outcome in older adults after total hip arthroplasty. *Neural Plast*. 2018;2018.
47. Perera S, Mody SH, Woodman RC, Studenski SA. Meaningful change and responsiveness in common physical performance measures in older adults. *J Am Geriatr Soc*. 2006;54:743–749.
48. Palombaro KM, Craik RL, Mangione KK, Tomlinson JD. Determining meaningful changes in gait speed after hip fracture. *Phys Ther*. 2006;86:809–816.
49. Barthuly AM, Bohannon RW, Gorack W. Gait speed is a responsive measure of physical performance for patients undergoing short-term rehabilitation. *Gait Posture*. 2012;36:61–64.
50. Alghadir A, Anwer S, Brismée J. The reliability and minimal detectable change of Timed Up and Go test in individuals with grade 1–3 knee osteoarthritis. *BMC Musculoskelet Disord*. 2015;16:174.
51. Wright AA, Cook CE, Baxter GD, Dockerty JD, Abbott JH. A comparison of 3 methodological approaches to defining major clinically important improvement of 4 performance measures in patients with hip osteoarthritis. *J Orthop Sports Phys Ther*. 2011;41:319–327.
52. Paravlic AH, Slimani M, Tod D, Marusic U, Milanovic Z, Pisot R. Effects and dose–response relationships of motor imagery practice on strength development in healthy adult populations: a systematic review and meta-analysis. *Sports Med*. 2018;48:1165–1187.
53. Eng XW, Brauer SG, Kuys SS, Lord M, Hayward KS. Factors affecting the ability of the stroke survivor to drive their own recovery outside of therapy during inpatient stroke rehabilitation. *Stroke Res Treat*. 2014;2014.
54. Lee GC, Song CH, Lee YW, Cho HY, Lee SW. Effects of motor imagery training on gait ability of patients with chronic stroke. *J Phys Ther Sci*. 2011;23:197–200.
55. Gentili R, Han CE, Schweighofer N, Papaxanthis C. Motor learning without doing: trial-by-trial improvement in motor performance during mental training. *J Neurophysiol*. 2010;104:774–783.
56. Guillot A, Collet C. Construction of the motor imagery integrative model in sport: a review and theoretical investigation of motor imagery use. *Int J Sport Psychol*. 2008;1:31–44.
57. Page SJ, Szaflarski JP, Eliassen JC, Pan H, Cramer SC. Cortical plasticity following motor skill learning during mental practice in stroke. *Neurorehabil Neural Repair*. 2009;23:382–388.
58. Dickstein R, Deutsch JE. Motor imagery in physical therapist practice. *Phys Ther*. 2007;87:942–953.
59. Nicholson VP, Keogh JWL, Low Choy NL. Can a single session of motor imagery promote motor learning of locomotion in older adults? A randomized controlled trial. *Clin Interv Aging*. 2018;13:713–722.
60. Grezes J, Decety J. Functional anatomy of execution, mental simulation, observation, and verb generation of actions: a meta-analysis. *Hum Brain Mapp*. 2001;12:1–19.
61. Jeannerod M. Neural simulation of action: a unifying mechanism for motor cognition. *Neuroimage*. 2001;14:S103–S109.
62. Courtine G, Papaxanthis C, Gentili R, Pozzo T. Gait-dependent motor memory facilitation in covert movement execution. *Cogn Brain Res*. 2004;22:67–75.
63. Beauchet O, Launay CP, Sejdić E, Allali G, Annweiler C. Motor imagery of gait: a new way to detect mild cognitive impairment? *J Neuroeng Rehabil*. 2014;11:66.