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Original article

Motor imagery does not effectively improve walking-related performance in older adults: A randomised controlled trial

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A B S T R A C T

Background: Inaccurate perception of one's physical abilities is potentially related to age-related declines in motor planning and can lead to changes in walking. Motor imagery training is effective at improving balance and walking in older adults, but most research has been conducted on older adults following surgery or in those with a history of falls. Deficits in motor imagery ability are associated with reduced executive function in older adults with cognitive impairment.
Objectives: To determine whether walking-specific motor imagery training could improve walking performance (physical and imagined) in healthy older adults, and identify the relationship between actual and imagined movement, motor imagery accuracy and executive function across 5 different walking tasks in healthy older adults.
Methods: A cohort of 53 community dwelling older adults took part in a 4-wk randomized controlled trial to assess the effect of motor imagery training on the physical and imagined performance of 5 walking-related tasks (3 narrow path walking tasks, Timed-up and go and step-over test), together with motor imagery clarity using the kinesthetic and visual imagery questionnaire (KVIQ-10). The association between physical performance, motor imagery accuracy and executive function were identified at baseline.
Results: Four weeks of motor imagery training did not improve walking-specific performance (imagined or physical) compared to no-training. Motor imagery training did improve the visual clarity of imagined non-walking tasks. Executive function was significantly correlated with 2 out of 5 imagined walking tasks and 4 out of 5 physical walking tasks but was not associated with motor imagery accuracy.
Conclusion: Four weeks of motor imagery training is not effective at improving performance in walking-related tasks in healthy older adults. This lack of improvement may be due in part to the high functional ability of the cohort. Future research should assess the relationship between motor planning and executive function with more complex walking tasks.
Trial registration: ANZCTR registration (ACTRN12619001784101).

Introduction

Impaired mobility, functional decline [1] and fear of falling [2] in older adults has been associated with age-related changes in motor planning and executive function [3]. Impaired or inaccurate perception of one's physical abilities can influence how a person interacts with their environment in everyday tasks such as walking and descending stairs. For example, underestimating one's own ability can lead to needless restriction of participation in physical and social activities [4] whereas overestimating one's own abilities is associated with risk-taking behaviour in older adults [5]. This mismatch between physical and perceived abilities (inaccurate perception) is thought to be related to an age-related decline in motor planning [2].

A simple approach to assessing the relationship between physical and perceived abilities is motor imagery. Motor imagery is the imagining of an action without its physical execution and elicits activity in brain regions that are normally activated during actual task performance [6]. Motor imagery is considered a valid method to assess motor planning and motor preparation [2,7] and is measured as the difference in spatial or temporal characteristics between an actual

List of abbreviations: ABC-6, short activities-specific balance confidence scale; KVIQ-10, 10 item kinesthetic and visual imagery questionnaire; KVIQ-V, visual component of the 10-item kinesthetic and visual imagery questionnaire; RAPA, rapid assessment of physical activity; RCT, randomised controlled trial; SOT, step-over test; TMT, trail making test; TMT-A, trail making test part A; TMT-B, trail making test part B; TUG, timed up and go

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and an imagined movement. It has been identified that low motor imagery ability (ie, larger differences in the time to complete physical and imagined tasks) is associated with reduced executive function [8–10] in young adults and in older adults with cognitive impairment.

Motor imagery training has been used to improve balance and gait speed [11,12] in older adults, particularly following orthopaedic surgery. Motor imagery training has also been associated with skill acquisition in young [13] and older adults [14] in novel upper limb tasks. These identified benefits are partly due to the promotion of motor memory and generation of an accurate motor plan that then improves physical performance [11,14]. Despite these findings, there has been limited work assessing the effect of motor imagery training on walking tasks in healthy older adults [15]. Rather, a number of studies have assessed misjudgement or impaired perception via motor imagery in older adults [16–18], and identified relationships between impaired perception and fear of falling [2,19] or falls risk [7,20], but none have assessed whether motor imagery training can positively influence perception (motor imagery accuracy) or physical function.

Furthermore, it is thought that motor imagery accuracy of complex walking tasks can provide insights into executive function in older adults as they rely more heavily on executive functions than young adults during complex motor tasks [21,22]. Indeed, previous work has shown that the role of executive functions in walking control is important, especially when navigating novel environments on foot [23,24].

Therefore, aims of this study were to:

1) Determine whether walking-specific motor imagery training could improve walking performance (both physical and imagined) and motor imagery accuracy in healthy older adults.
2) Identify the relationship between actual and imagined movement across 5 different walking tasks in older adults.
3) Identify the relationship between motor imagery accuracy and executive function across 5 different walking tasks in older adults.

Method

Design

We conducted a randomised controlled trial between June and August 2021.

Ethical and regulatory aspects

The study was prospectively registered through the Australian and New Zealand Clinical Trial registry (ACTRN12619001784101) and received ethical clearance through the Human Research Ethics Committee of the Australian Catholic University. The CONSORT guideline was followed for the reporting (Supplementary Material).

Participants

Community dwelling older adults were recruited from Brisbane, Australia. To be included, participants needed to be aged at least 65 years, be independent and community dwelling, be able to walk at least 10m without assistance, have access to a digital device at home (eg, smart phone or computer) and willing to commit to the study requirements. Exclusion criteria: acute or terminal illness, unstable or ongoing cardiovascular and/or respiratory disorder, progressive neurological disease or impairment, joint replacement surgery in the past 6 months, cognitive impairment, or the inability to commit to study periods. An initial telephone screening was used to determine eligibility. Relevant sociodemographic and clinical variables, including age, cognition (MiniCOG) [25], gender, number and type of medication, physical activity level (RAPA) [26], and education level were recorded at baseline.

Assessment

Testing of all primary and secondary outcome measures was conducted at baseline and immediately after a 4-wk intervention/control period in a laboratory setting in Brisbane, Australia. For the timed up and go (TUG) test, walking speed (on narrow walking paths) and step-over test, all imagined and physical tasks were completed twice, and the mean score of the 2 trials was used in the analysis. Participants completed imagined tasks prior to completing physical tasks. The participants completed the TUG, then narrow walking paths (in random order), then the step-over test.

Primary outcome measure

Timed up and go test

The TUG test has been widely used and validated as a motor imagery task in older adults [27]. For the imagined task (iTUG), which was performed before the physical task, participants sat in a chair (~44cm height). A marker was placed 3 metres in front of the chair and participants were instructed to imagine performing a TUG trial without actual physical movement and to estimate the time taken to complete the trial. Participants were instructed to imagine themselves completing the task from a first-person perspective, walking at their normal, comfortable speed. Timing started on the command “ready, set, go” and stopped when the participant said the word “stop”, which corresponded with the person returning to sitting with their back against the back rest (in their imagination). Time was recorded (to the nearest 1/100th second) using a digital stopwatch.

For the actual/physical task (aTUG), participants were instructed to complete the TUG at their normal, comfortable walking speed [28]. Time was recorded (to the nearest 1/100th second) using a digital stopwatch. Participants did not receive any feedback for either the iTUG or aTUG results during the TUG task. The difference (TUGdelta) between iTUG and aTUG time was then calculated to determine the motor imagery accuracy of the TUG: *([actual time – imagined time]/[actual time + imagined time/2])*$\times$*100.* A positive TUGdelta represents a tendency to underestimate the actual TUG time (ie, overestimate physical performance). The iTUG (and TUG delta) have been used extensively to assess higher level gait and to identify mild cognitive impairment in older adults [27,29]

Secondary outcomes

Walking speed

Walking speed was assessed over a 5-metre path of 3 varying widths (15, 25, and 50 cm) [30,31]. Each path width (and length) was designated by coloured tape adhered to the floor. First, participants stood in front of one type of walkway and imagined walking along it from a 1st person perspective at their normal, comfortable speed. Participants were instructed to imagine themselves stepping accurately within the coloured tape. Timing started on the command “ready, set, go” and stopped when the participant said the word “stop”, which corresponded with them taking their first step out of the walking zone (in their imagination). Time was recorded (to the nearest 1/100th second) using a digital stopwatch. Walkways were presented in a random order and participants imagined walking along each path twice.

For the actual/physical task, participants stood in front of one type of walkway and physically walked along it at their normal walking speed. Participants were instructed to avoid stepping outside the coloured tape designating the path. The trial was repeated if a participant took more than 1 step outside the designated path while walking. Timing started on the command “ready, set, go” and stopped when the participant took their first step out at the end of the 5-m walking path. Time was recorded (to the nearest 1/100th second) using a digital stopwatch. The participant then walked along the remaining 2 types of walkways, with the walkways presented in a random order. The difference (delta) between actual and imagined walking time was then calculated to determine the accuracy of the motor imagery of walking speed on each path (15cm delta, 25cm delta and 50cm delta): *([actual time − imagined time]/[actual time + imagined time/2])×100.* A temporal relationship has been identified between physical and imagined narrow path walking previously in older adults [31,32].

Step-over test (SOT)

A white plastic bar (25 × 25 × 900 mm) attached to 2 plastic poles with adjustable sliding brackets was used for measuring step-over ability. The SOT device was placed 2 m away from a white wall [33]. A metal measuring tape was used to measure the bar height. The white plastic bar could be easily knocked from the brackets once touched by a participant to prevent participants from falling. Bar height was adjusted between 10 and 90 cm.

Participants were asked to observe the bar from 7 m while standing. The chief investigator manually and slowly adjusted the height of the bar either from 10 to 90 cm (ascending) or from 90 to 10 cm (descending). While the bar was moving, participants were asked to say “stop” at the point where they believed the bar had reached the maximum height that they could safely step over without using their hands. Participants were instructed to imagine stepping over the bar from a 1st person perspective, with their bodies facing straight ahead without jumping (ie, they could abduct and rotate their hips as long as they kept their body facing forward), and no restrictions to walking speed. They were allowed to amend their estimated height after the experimenter manually adjusted the bar height. Two ascending and 2 descending trials were conducted. The average of these trials was used to determine the imagined step-over-test (iSOT) height. Participants received no feedback while performing the imagined iSOT.

For the actual step-over test (aSOT), the bar was placed at the participants’ iSOT height, and participants were asked to approach the bar and step over it. If a participant failed to step over the bar (ie, touched/kicked the bar with the foot/lower limb) at the iSOT height, the bar was lowered by 3 cm. Alternatively, if the participant succeeded at the iSOT height, the bar was raised by 3 cm. Participants were then asked to step over the bar again at the new height. This was repeated until they either succeeded or failed the step-over action, and the final height at which participants were successful during 2 consecutive trials was recorded as the individual actual maximum height (aSOT). The difference (SOTdelta) between iSOT and aSOT height was then calculated to determine the motor imagery accuracy of the SOT. To normalise for individual lower limb length, iSOT and aSOT were divided by the length of each participant’s lower limb (distance from the greater trochanter to the ground through the lateral malleolus). Calculation of motor imagery accuracy (normalised to lower limb length) was determined by the established formula [20,33,34]: *SOTdelta = (iSOT − aSOT)/aSOT ×100.* Overestimation on the step-over test has been associated with reduced physical ability and falling in older adults [20,34].

Trail making test (TMT) part A and B

The Trail Making Test was used to evaluate the cognitive flexibility/set-shifting aspect of executive function [35]. The TMT has good to excellent test-retest reliability in older adults [36] and has been used to identify the relationship between motor imagery and motor planning/executive function previously [10,34]. The time to complete Part B (more challenging) was used for analysis [35].

The short activities-specific balance confidence (ABC-6) scale

The ABC-6 was used to assess balance confidence [37]. This outcome was included as it has been found that higher levels of fear-related psychological concern are associated with poor motor imagery ability in older adults [7].

The kinesthetic and visual imagery questionnaire (KVIQ-10)

The KVIQ -10 was used to assess the clarity of visual images and the sensations associated with different physical tasks. It is a valid and reliable tool [38] that has been used to assess motor imagery ability in healthy adults and neurological participants. This outcome was included to identify whether motor imagery clarity of untrained tasks improved after motor imagery training.

Group allocation and randomisation. To identify whether motor imagery training could influence physical and imagined walking performance, a 4-wk randomized controlled trial was conducted. After the baseline assessment, participants were randomly assigned to the motor imagery or control group. Participants were randomly assigned via block randomisation procedures (blocks of 4). An opaque envelope contained 4 pieces of paper (a block) with a printed letter (A or B), with A representing the control group and B the experimental group. The blocks were produced a priori by the chief investigator. Each participant withdrew a printed piece of paper from an opaque envelope in the presence of a research assistant. Based on their selection, the research assistant would then either provide the participant with the motor imagery training package for those in the experimental group (ie, videos, training scripts, training diary) or would simply inform participants in the control group to continue with their everyday activities. The research assistant was not involved with collection of primary outcome data or data analysis. The chief investigator assessed primary outcomes and was blinded to group allocation.

Motor imagery Intervention. Participants in the motor imagery group completed unsupervised action observation plus motor imagery training 5 times per week for 4 wk and were encouraged to continue with their usual activities. Action observation is a cognitive training method that induces motor learning through observation of other people’s performance [6]. Action observation was included in the intervention as action observation combined with motor imagery appears to be more effective than motor imagery alone [39]. Each training session lasted approximately 15 minutes. Participants in the motor imagery group performed the training at home (using a smart phone, tablet or computer) with the assistance of instructional videos (action observation) with narrated guidance. The instructional videos were provided to participants on a USB (for those using a computer) or were downloaded onto their portable device. The motor imagery programme consisted of 5 activities that incorporated videos of a 70-year-old female completing the following walking tasks: walking on uneven ground; walking up large steps; “tightrope” walking; walking on large stepping-stones; and walking on a foam balance beam. Participants were instructed to first watch the prescribed video then imagine themselves performing the activity from a first-person perspective. Each training day typically involved the participant completing 3−6 laps/sets of 4 activities (see Supplementary Material for details). Participants were provided with an instruction booklet, training schedule and a training diary to monitor adherence to the programme.

Control group

Participants in the control group did not receive any motor imagery training intervention or sham training intervention. They were instructed to continue with their usual activities and not to commence any new exercise regime or physical activity (as this may lead to improvements in physical performance).

Statistical analysis

An a priori power calculation was conducted using G*Power (3.1.9.6) to identify a medium-large effect size between groups in the primary perception outcome of TUG (80% power, P <0.05). A sample size of 46 (23 per group) was required. To account for a 10% loss to follow-up, we aimed to recruit a total of 52 participants (26 per group). This estimated sample size was based on previous perception studies [41] in older adults and motor imagery training studies of improvements in walking [12].

All statistical analyses were conducted using IBM SPSS (Version 27). Statistical significance was set at P <0.05. All primary and secondary outcomes were tested for normality using the Shapiro-Wilk test. Mann-Whitney U tests were used to identify any between group differences in primary and secondary outcomes following the 4-wk intervention for non-parametric data (ANOVA used if parametric data). For the randomised controlled trial (RCT), data were analysed using the intention to treat principle.

The strength of association between each walking-related task (imagined, actual and deltas for each task) and executive function (TMT) at baseline was measured using Spearman's rho. Effect sizes of correlations were based on Cohen's rule of thumb [40] (0.1 = small/weak, 0.3 = medium/moderate and 0.5 = large/strong).

Results

Fifty-three community dwelling older adults with a mean age of 75.5 (6.4) years (35 females) took part in the study (Table 1). Follow-up testing was completed by 48 participants (24 in each group) (Fig. 1). There were baseline differences between the groups for iTUG and TUG delta, with the MI group having a higher iTUG score and lower (more accurate) TUG delta than the control group. There were no differences in any other any primary or secondary outcomes or demographic variables (Table 1). The majority of outcomes were not normally distributed so the Mann-Whitney U test (non-parametric test) was used to identify between group differences.

Effect of motor imagery training

There were no differences between groups for change scores for any primary outcome measure. For secondary outcomes, there was a significant group difference in the kinaesthetic and visual imagery questionnaire—visual component (KVIQ-V) score change in favour of the motor imagery group (Mann-Whitney U = 242.5, P = 0.048) suggesting that the visual clarity of imagined tasks had improved in the motor imagery group.

Adherence to motor imagery training

High levels of adherence were reported by those that completed the programme and attended post-testing with the mean (SD) number of sessions completed being 19.7 (1.4) sessions out of a prescribed 20. When including the 3 participants who withdrew after completing 0 sessions the level of adherence was still >85% - mean of 17.5 (6.4) sessions.

Correlations

Relationship between imagined movement tasks. The iTUG and all imagined walking path tasks (i50cm, i25cm, i15cm) were significantly correlated with each other. The iSOT was significantly correlated with the iTUG but not with any walking path task (Table 2).

Relationship between actual movement tasks. Actual task performances were significantly correlated between all tasks (Table 3).

Relationship between deltas (difference between imagined and actual tasks). The TUGdelta and walking path deltas were all significantly correlated with each other but the SOTdelta was not significantly correlated with any other delta measure (Table 4).

Imagined and actual task performance relationship. Imagined and delta measures were not normally distributed so Spearman's rho was used to determine bivariate correlations. Within each walking-related task, the imagined and actual task performance were significantly correlated (TUG rho = 0.796, P <0.001; 50 cm rho = 0.639, P <0.001, 25 cm rho = 0.649, P <0.001, 15 cm rho = 0.733, P <0.001, SOT rho = 0.701, P <0.001).

Relationship between performance tasks and executive function. TMT-B had a significant positive correlation with iTUG (rho 0.35, P = 0.009), aTUG (rho 0.45, P = 0.001), a25cm (rho 0.31, P = 0.026), i15cm (rho 0.29, P = 0.032), a15cm (rho 0.39, P = 0.004) and a significant negative correaltion with aSOT (rho −0.31, P = 0.02) (Table 2 and 3). TMT-B did not have a significant correlation with any delta value (Table 4).

Discussion

Effect of motor imagery training

The primary aim of this study was to identify whether walking-specific motor imagery training could improve walking-related performance (both physical and imagined) in healthy older adults. We found that 4 wk (total training = 5 hours) of motor imagery training did not improve walking-related performance or motor imagery accuracy (as determined by motor imagery deltas). Most previous motor imagery interventions in older adults have not assessed task specific motor imagery ability after training, primarily as the study aims were to improve physical abilities such as strength, balance and walking speed [12]. In one of the few intervention studies that assessed changes in motor imagery ability, Zapporoli et al reported an improvement in TUGdelta following motor imagery training in participants after knee replacement surgery [11]. Importantly, these improvements in TUGdelta were largely due to improvements in physical performance post-operatively rather than pure improvements in accuracy of imagined performance – that is, the physical performance got quicker while imagined times remained similar, resulting in a more accurate perception (lower TUGdelta). In our current study, it was expected that any improvements in TUGdelta derived from training would be due to an improvement in motor imagery accuracy as we recruited community dwelling older adults, meaning there would be less opportunity for physical improvement compared to a post-operative or inactive cohort. It appears that due to the accurate prediction at baseline, there was very little room for improvement following motor imagery training. For example, the mean TUGdelta of 11% in the motor imagery group is more accurate than the 31% previously identified in a large cohort of healthy older adults [42]. Furthermore, the TUGdelta of the MI group was significantly lower than that of the controls at baseline, suggesting little room for improvement was possible in TUGdelta. Similarly, the walking path delta of <10% is more accurate than that previously identified for older adults across the 50, 25 and 15cm walking paths [18]. Alternatively, it could be argued that the motor imagery training tasks did not match the motor imagery assessment tasks. This was done intentionally to ensure that participants in the motor imagery group were practicing functional walking tasks rather than simply rehearsing the outcome measures used in our study.

Most motor imagery training studies have previously focused on older adults with neurological conditions such as stroke [43] or following orthopaedic surgery [11], or have assessed relationships between motor imagery ability and falls/fear of falling [2,7,18,20,31,34]. By recruiting community dwelling older adults, our study assessed the effectiveness of motor imagery training in older adults without evident physical (or cognitive) limitations. It is possible that the motor imagery training was not intensive enough to

Table 1
Participant characteristics and between group comparisons.

Variables	MI group baseline (n=27)	Control group baseline (n=26)	MI group post (n=27)	Control group post (n=26)	Between group change *P* value
Age	74.5 (6.3)	76.6 (6.4)			
Height (m)	1.69 (0.08)	1.68 (0.1)			
Weight (kg)	77.3 (16.0)	74.7 (13.6)			
BMI	27.1 (5.1)	26.6 (4.3)			
Medications (n)	2.9 (2.4)	2.7 (3.0)			
Mini-Cog	4.7 (0.5)	4.7 (0.5)			
RAPA	5.4 (1.2)	5.0 (1.4)			
iTUG (secs)	9.3 (4.0)	7.6 (4.5)[b]	9.6 (4.6)	7.7 (3.4)	0.327
aTUG (secs)	10.9 (3.7)	9.5 (2.6)	10.5 (2.8)	9.2 (2.5)	0.131
TUG delta	12 (14)	18 (22)[b]	9 (21)	14 (17)	0.473
i50cm walk (secs)	7.3 (3.7)	6.5 (3.2)	7.3 (4.1)	6.5 (3.6)	0.999
a50cm walk (secs)	6.0 (1.9)	5.5 (1.4)	5.7 (1.2)	5.4 (1.6)	0.262
50cm walk delta	−10 (22)	−7 (26)	−13 (24)	−7 (24)	0.593
i25cm walk (secs)	8.5 (4.8)	6.7 (3.0)	9.0 (5.9)	7.0 (3.4)	0.804
a25cm walk (secs)	7.5 (4.8)	6.1 (2.0)	6.7 (2.4)	5.9 (1.6)	0.352
25cm walk delta	−8 (23)	−5 (22)	−15 (22)	−8 (22)	0.530
i15cm walk (secs)	11.5 (7.9)	8.8 (5.7)	11.6 (7.6)	9.3 (6.0)	0.784
a15cm walk (secs)	9.6 (7.8)	7.6 (3.5)	9.9 (7.1)	7.1 (2.6)	0.341
15cm walk delta	−13 (29)	−6 (24)	−11 (25)	−12 (29)	0.172
iSOT (cm)	38.3 (9.6)	37.9 (10.8)	44.5 (8.6)	43.5 (12.7)	0.766
aSOT (cm)	56.6 (10.7)	55.4 (10.9)	58.3 (9.2)	55.0 (12.2)	0.146
SOT delta	−32 (15)	−32 (11)	−24(10)	−21 (13)	0.310
TMT-A (secs)	35.8 (14.3)	33.0 (9.8)	31.0 (9.4)	30.1 (9.1)	0.450
TMT-B (secs)	84.8 (37.8)	80.5 (26.3)	76.2 (33.8)	73.3 (25.2)	0.823
TMT-B percentage based on age and education[a]	79 (32)	71 (24)	72 (31)	64 (21)	0.852
ABC6	75.7 (16.7)	74.6 (21.5)	75.3 (15.5)	73.4 (19.1)	0.965
KVIQ-V score per item	3.5 (1.0)	3.7 (1.2)	3.9 (1.1)	3.7 (1.1)	0.048[c]
KVIQ-K score per item	2.9 (1.0)	3.0 (1.1)	3.3 (1.0)	3.2 (0.9)	0.733
KVIQ-10 total	32.4 (9.3)	33.4 (9.1)	35.8 (9.3)	34.6 (8.4)	0.133

Data are mean (SD).
50cm walk delta, difference between imagined and physical 50cm walk; 25cm walk delta, difference between imagined and physical 25cm walk; 15cm walk delta, difference between imagined and physical 15cm walk; a50cm walk, time to complete actual 50cm width walking path; a25cm walk, time to complete actual 25cm width walking path; a15cm walk, time to complete actual 15cm width walking path; ABC6, activities specific balance confidence scale 6 item version; aSOT, step-over test actual height; aTUG, actual timed up and Go; i50cm, time to compete imagined 50cm width walking path; i25cm walk, time to compete imagined 25cm width walking path; i15cm walk, time to compete imagined 15cm width walking path; iSOT, step-over test imagined height; iTUG, imagined timed-up and Go; kg, kilograms; KVIQ-10, the kinesthetic and visual imagery questionnaire; KVIQ-K, the kinesthetic and visual imagery questionnaire kinesthetic component; KVIQ-V, the kinesthetic and visual imagery questionnaire visual component; LL, leg length; m, metres; RAPA, rapid assessment of physical activity; SOT delta, difference between imagined and physical step-over height; TMT-A, trail making test part A; TMT-B, trail making test part B; TUG delta, difference between iTUG and aTUG.

[a] Based on Tombaugh 2003 normative data (a score over 100 means superior to normative data).
[b] Significant difference between groups at baseline $P < 0.05$.
[c] Significant difference between groups for change score $P < 0.05$.

influence motor imagery accuracy or physical performance. Although the total prescribed training of 5 hours (15 minutes × 5 per week × 4 wk) was longer than most previous motor imagery interventions in older adults [12] and similar to that used in rehabilitation settings [44], as participants did not have an evident limitation in their motor imagery or physical ability, a more intensive (or longer) training programme may be necessary to elicit changes in this cohort with accurate motor planning abilities. Finally, despite including the SOT, which challenges dynamic single leg balance, and narrow path walking, which challenges medio-lateral dynamic balance, the inclusion of more novel and challenging walking task outcomes may be required to identify improvements in high-functioning older adults.

There was a significant group difference in KVIQ-V score change favouring the motor imagery group. This result indicates that the subjective images produced by motor imagery participants after training were clearer than the control group at follow-up for non-walking tasks (as the tasks in the KVIQ relate to movements while seated). No such differences between groups were observed for motor imagery accuracy relating to walking tasks as there were no differences in the deltas between groups (eg, TUGdelta). This contrasts with previous work in participants with orthopaedic disorders, where improvements in TUGdelta were identified after action observation and motor imagery training focusing on walking [11], however, the improvements in TUGdelta (termed motor imagery quality index in that study) were largely driven by the greater improvement in the physical TUG in the motor imagery group compared to controls.

Relationship between imagined tasks

There were inconsistent relationships between imagined tasks, with the iTUG being correlated to all other walking-related tasks. These results suggest that the iTUG shares motor planning characteristics with both narrow path walking and step-over tasks but the SOT may require more specific/familiar motor planning than flat ground walking. This may be simply explained by the TUG and walking path tasks relying on a consistent, habitual motor plan (ie, flat ground walking) that is refined and updated regularly with usual walking activities. In contrast, most older adults do not commonly step-over very large hurdles or similar obstacles (at the limits of their abilities), as such an accurate motor plan cannot be drawn upon to provide an accurate perceived state. This has been identified previously where in order to use an internal perspective during motor imagery of a

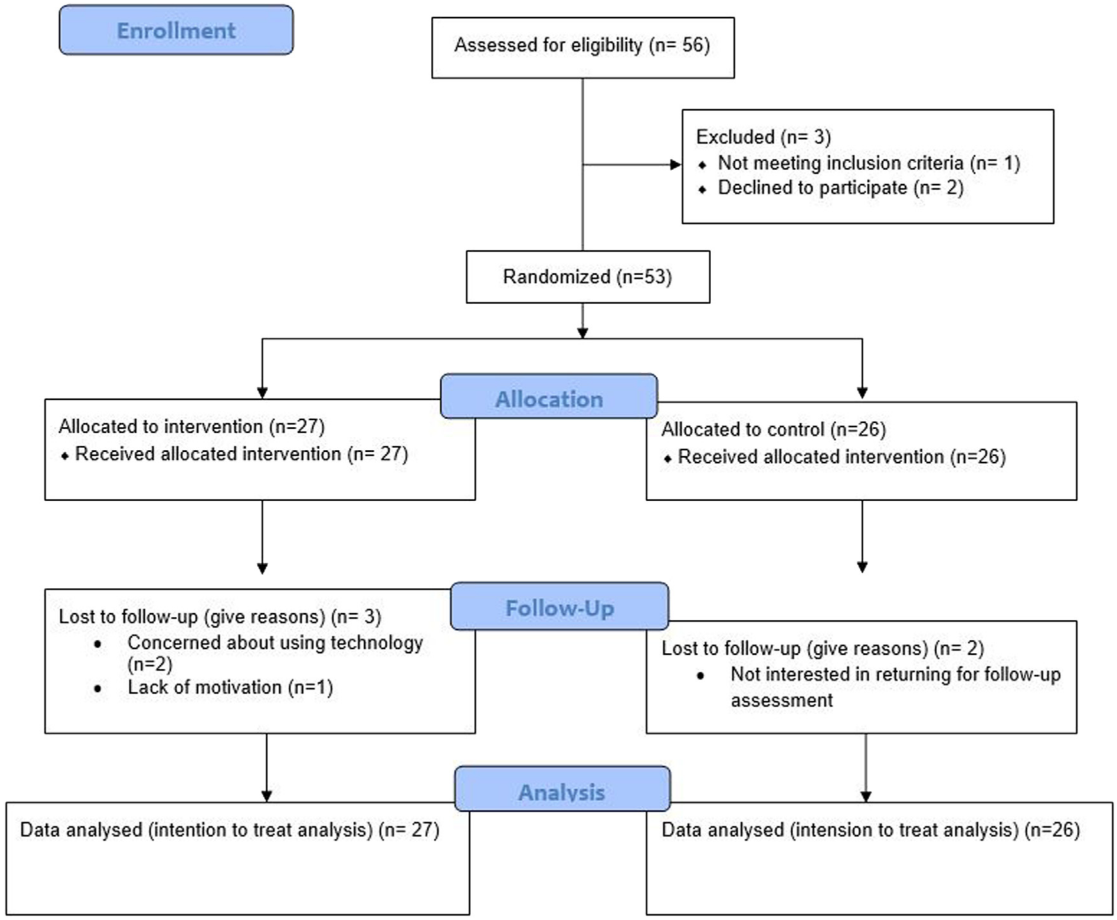

Fig. 1. CONSORT flow diagram.

complex skill, one must have well established motor representations of the skill which then translates into an internal plan [45,46].

Relationship between task deltas

The deltas (difference) of the TUG and walking paths were all significantly correlated with each other but the SOTdelta was not significantly correlated with any other delta measure. It has been suggested that one's degree of misjudgement (or accuracy) is not an inherent trait and should be considered as a task-dependent measure [16]. As both the TUG and narrow walking path tasks are flat ground walking tasks, it stands to reason that the correlation between accuracy in these tasks is stronger than that of the SOT. In both the TUG and walking path tasks, participants were very accurate in their own assessments (ie, motor imagery accuracy/perception) with deltas being less than 15%. Participants were less accurate in their perception of the SOT where they underestimated actual stepping height by ~30%, which may again be partly due to the unfamiliar nature of the SOT compared to flat ground walking, thereby reducing the participants affordance perception [47]. This 30% underestimation is larger than the 11% underestimation found previously in a similarly aged cohort [33]. It appears that this high-functioning cohort in our study were very conservative about their own ability to step-over a hurdle. No participant in our study overestimated their ability in the SOT as all participants were able to physically step-over their estimated height which contrasts with previous research where up to 30% of older adults overestimated their step-over ability [20,33]. This may

Table 2
Correlations between imagined tasks and TMT-B at baseline.

	iTUG	i50cm	i25cm	i15cm	iSOT	TMT-B
iTUG						
i50cm	**0.724					
i25cm	**0.728	**0.947				
i15cm	**0.767	**0.884	**0.907			
iSOT	*−0.289	−0.258	−0.253	−0.183		
TMT-B	*0.345	0.233	0.228	*0.294	−0.214	

i50cm, time to compete imagined 50cm width walking path; i25cm, time to compete imagined 25cm width walking path; i15cm, time to compete imagined 15cm width walking path; iSOT, step-over test imagined height; iTUG, imagined timed-up and Go; TMT-B, trail making test part B, *significant $P < 0.05$, **significant $P < 0.01$.

Table 3
Correlations between actual tasks and TMT-B at baseline.

	aTUG	a50cm	a25cm	a15cm	aSOT	TMT-B
aTUG						
a50cm	**0.785					
a25cm	**0.822	**0.902				
a15cm	**0.757	**0.705	**0.874			
aSOT	**−0.448	*−0.342	*−0.289	**−0.355		
TMT-B	**0.448	0.179	*0.306	**0.392	*−0.312	

i50cm, time to compete imagined 50cm width walking path; i25cm, time to compete imagined 25cm width walking path; i15cm, time to compete imagined 15cm width walking path; iSOT, step-over test imagined height; iTUG, imagined timed-up and Go; TMT-B, trail making test part B, *significant $P < 0.05$, **significant $P < 0.01$.

Table 4
Correlations between task deltas and TMT-B at baseline.

	TUG delta	50cm delta	25cm delta	15cm delta	SOT delta	TMT-B
TUG delta						
50cm delta	**0.552					
25cm delta	**0.453	**0.793				
15cm delta	**0.480	**0.703	**0.685			
SOT delta	0.178	−0.069	−0.046	−0.118		
TMT-B	−0.158	−0.176	0.016	0.001	0.069	

i50cm, time to compete imagined 50cm width walking path; i25cm, time to compete imagined 25cm width walking path; i15cm, time to compete imagined 15cm width walking path; iSOT, step-over test imagined height; iTUG, imagined timed-up and Go; TMT-B, trail making test part B, *significant $P<0.05$, **significant $P<0.01$.

indicate that this cohort is a generally low risk-taking group, which may be partly why they were largely a group of non-fallers. Indeed, previous research has identified that older adults with low frequency of going outdoors [33], fear of falling [33] and those with poor physical ability are more likely to overestimate their ability [48]. It is clear from previous research that motor imagery training can be effective when an individual has an impairment, it is also possible that a greater level of overestimation (inaccuracy) in walking-related tasks may be necessary to have an opportunity to improve both motor imagery accuracy and further improve physical performance.

Relationship between physical tasks

For the physical performance, all tasks were significantly correlated with each other, although the strength and direction were influenced by the step-over task. For example, the TUG and walking path tasks were strongly positively correlated with each other whereas the step-over task was moderately and negatively correlated with the TUG and walking path tasks. Similar strong correlations have been identified in previous work comparing different motor imagery stepping tasks [16]. The slightly weaker correlations between the SOT and walking tasks may be due to the SOT being more reliant on single limb balance, hip strength, and hip and knee mobility than the walking tasks [49], thereby introducing a constraint not evident in the other tasks.

Relationship between motor walking-related tasks and executive function

Our study was the first to assess the relationship between mulitple walking-related tasks (imagined and physical) and executive function [10,34]. The TMT-B was significantly correlated with some imagined (iTUG, i15cm) and physical tasks (aTUG, a25cm, a15cm and aSOT), there was no significant relationship between TMT-B and any of the task deltas. This is in contrast to others [10] who found a significant correlation between TUG delta and TMT-B (r = 0.364, $P<0.01$) in those with MCI or subjective cognitive impairment. Our results better reflect those found by Sakurai et al who did not find a significant relationship between SOTdelta and TMT-B in their similarly aged and cognitively healthy cohort [34], and further identified no significant relationship between TMT-B and TUGdelta or and narrow path walking deltas. The high-functioning nature of this current cohort and limited within group variablity may have limited the ability to identify a relationship between TUGdelta and TMT-B. For example, the mean TMT-B time of 82.7seconds is ~20s quicker than previoulsy identified for similar aged cohorts [7,33]. When accounting for individual age and education level, the current cohort's mean TMT-B time was ~25% faster than established normative data in older adults [50]. Further, the TUGdelta of 15 ± 19% in this cohort is some 15−25% smaller than other older adult cohorts [42]. Taken together, this indicates that the current cohort had a very accurate perception of their own walking ability (ie, accurate motor imagery) which likely relates to accurate motor planning, which is supported by the excellent TMT-B times. Alternatively, it may simply be that both physical and imagined versions of complex walking tasks are better indicators of motor planning or motor prediction than the delta of the physical and imagined task in healthy older adults.

Strengths and limitations

We used an easy-to-use motor imagery training programme that was completed independently, was well adhered to by participants and there were no adverse unintended negative effects. Older adults were recruited via community organisations (such as Rotary, Probus and walking groups, older adult education providers), typically via electronic means (email, Facebook forums) which meant that older adults that may not have access to email or social media are unlikely to have taken part. Therefore, this study primarily recruited a community engaged, technology savvy and high-functioning cohort that are not likely to be representative of older adults. Consequently, the results of this study are likely to be generalisable to high-functioning older adults only. This study was the first to assess the relationship between multiple walking-related motor imagery assessments and executive function in older adults. The study was limited by a small sample size which resulted in the observed power being less than 0.5 for some outcomes.

Practical implications

The results of this study suggest that motor imagery training is not effective for older adults without evident physical limitations or impairments in walking-related tasks. The training intervention may not have been intensive enough to elicit changes in motor imagery accuracy or function in this healthy cohort so it may be necessary to re-design the training intervention to make it more intense and longer in duration, or to include more complex walking outcomes so that larger changes occur.

Conclusion

In a cohort of healthy older adults without evident walking impairments, motor imagery training does not improve physical or imagined performance in walking tasks. It appears that both physical and imagined versions of complex walking tasks are more closely related to executive function than motor imagery accuracy (ie, diffference between imagined and physical performance). Motor imagery accuracy of walking-related tasks is not associated with executive function in healthy older adults who have a very accurate perception of their own ability in walking-related tasks. Future research should assess the relationship between motor planning and executive function with more complex walking tasks in healthy older adults and should compare the effectiveness of more intensive training intreventions in healthy older adults.

Declaration of competing interest

None.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.rehab.2024.101899.

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