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**Effects of motor learning interventions on walking performance and physical function in older adults with cognitive impairment and dementia: a systematic review and meta-analysis**

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**Abstract**

Older adults with cognitive impairment have deficits in executive systems that affect their gait automaticity. The aim of the meta-analysis and systematic review was to examine the effects of gait interventions focus on only motor learning principles on gait performance and physical functions (e.g, dynamic balance). We used the PRISMA checklist and guidelines to review the studies. After inspections of 879 articles, 11 relevant studies were selected for systematic review and meta-analysis. The PEDro scale and Modified Downs and Black checklist were used to assess the quality of studies and a random-effect model was used at a 95% confidence interval for calculating pooled effect sizes. The results of this systematic review and meta-analysis showed motor learning interventions increased gait speed, cadence, stride length, and reduced gait cognitive cost but did not affect gait variability and physical function. In conclusion, practitioners should pay attention more to the potential benefits of motor learning interventions in rehabilitating older adults with cognitive impairment.

Keywords: cognitive impairment, gait training, executive system function, synthesis review.

## Introduction

The ageing population is growing globally due to changes in people's lifestyles and improved access to health care services. The increased number of the ageing population might need more special services due to debilitating changes in different body systems that lead to functional declines in the activity daily living (ADL) of some older adults including impairment in cognitive functions, the decline in walking performance, losing postural stability and increased risks of fall (Ferrucci et al., 2016). The burden of hospitalisation due to cognitive declines is also significant. For instance, it is estimated that by 2050, 135 million people will have dementia worldwide which could increase the cost of hospitalisation from £396bn in 2010 to £650bn by 2030 (M Prince, Prina, & Maëlen, 2013).

Dementia is described as a clinical syndrome that encompasses problems in memory, executive systems and behaviours that could adversely affect independence and interpersonal interactions (Robinson, Tang, & Taylor, 2015). The main clinical feature of cognitive impairment is an impairment that primarily affects different domains including the executive system, attention, language and learning, memory recall and perceptual-motor skills (Waldemar et al., 2007). Declines in the executive system, attention and perceptual-motor skills are closely associated with motor disorders such as walking decline and postural instability (Sachdev et al., 2014).

The close connections between gait performance and cognition are supported by evidence from imaging studies that showed cognition and gait share the same neural networks that are mediated by frontal subcortical circuits and are responsible for planning, working memory, attention and motor control (Bonelli & Cummings, 2007). Hence, any structural and functional declines in these regions of the brain could affect gait parameters and subsequently postural stability. The associations between cognition and motor functions are even stronger in people with dementia and older adults because, unlike young people, the

cortical regions are more actively involved during walking which makes the walking task more attention-demanding, conscious and less automatic. Walking gait requires more attentional resources for successful body transportations specifically in the situations in which the person needs modifications in gait patterns in the presence of obstacles or directional changes (Beauchet & Berrut, 2006).

People with dementia usually show high-level pathological gait disorders that are exhibited by cautious gait, decreased walking speed and stride length and increased support time (Martin & O'Neill, 2004; Nutt, 2001; Waite et al., 2005). Several studies in adults aged 70 and older have shown that gait and motor disorders are predictors of cognitive impairment and the gait declines such as walking speed and gait variability were present at the early stage of dementia (Amboni, Barone, & Hausdorff, 2013; Verghese et al., 2002; Verghese, Wang, Lipton, Holtzer, & Xue, 2007). Gait declines in early-stage dementia implies the diagnosis of cognitive impairment through gait observation and assessing postural stability could help clinicians in the early diagnosis and prevention of cognitive declines and dementia in community-dwelling older adults (Martin Prince, Bryce, & Ferri, 2018).

The main aim of any gait training in older adults with cognitive impairment is to regain automaticity by reducing the cognitive costs and multi-task interference (Belghali, Chastan, Cignetti, Davenne, & Decker, 2017). Generally, gait automaticity is characterised by three main features. First, the automatic processing is fast and parallel, whereas controlled processing is slow and serial. Second, automatic processing is effortless and can operate in high workload situations, whereas controlled processing requires substantial effort and the cost of multi-tasking is high. Third, the automatic processing relative to controlled processing is less sensitive to stressors and environmental conditions are less challenging and deteriorative to walking performance (Schneider & Chein, 2003).

The scopes of review studies that focused on gait interventions in older adults with dementia were diverse and included physical-cognitive (Alexander, Gaydos, Walch, & McCallum, 2019), virtual reality (Zhu et al., 2021), mind-body interactions such as Tai Chi (Farhang, Miranda-Castillo, Rubio, & Furtado, 2019), dual-tasking (Bishnoi & Hernandez, 2020), music cued (Gomaa, Wittwer, Grenfell, Sawan, & Morris, 2018) and multicomponent interventions that were a combination of strength training, flexibility and walking tasks (Machado et al., 2020). But, the abovementioned interventions did not directly focus or separate the underlying mechanisms of gait automaticity (e.g. timing, coordination, planning and decision-making, etc.) that usually are improved through motor learning interventions. For example, even dual-task interventions, as an index of attention and automaticity (Bishnoi & Hernandez, 2020) and task-oriented gait practice (Brach, Van Swearingen, Perera, Wert, & Studenski, 2013), were used in conjunction with physical and motor fitness programmes and it is difficult to assess whether the interventions that merely associated with automaticity were effective on gait performance and ADLs in people with cognitive impairment.

As executive system and motor function deficits are partly responsible for the impairment of planning motor skills and ADLs in people with cognitive impairment, the interventions that implicitly or explicitly focus on motor behaviours rehearsal are more effective to regain motor automaticity (van Halteren-van Tilborg, Scherder, & Hulstijn, 2007). Generally, the explicit methods emphasise declarative learning through knowing the action idea, whereas the implicit methods emphasise procedural learning and through unconscious and lack of person's awareness (R. A. Schmidt & Wrisberg, 2008). The available evidence on the effectiveness of implicit and explicit motor learning interventions on tasks other than gait in people with cognitive impairment (e.g. Alzheimer's disease (AD) and dementia) is promising (Dick et al., 2001; Dick, Hsieh, Bricker, & Dick-Muehlke, 2003; Zanetti et al., 2001). For example, Zanetti et al showed that patients with AD were able to

learn how to use a telephone when the implicit learning method rather than the explicit method was used (Zanetti et al., 2001). Dick et al showed that the benefit of constant practice was more than random practice in older adults with AD because the repeated running of the same motor programme does not require an intact episodic memory and is less attention-demanding (Dick et al., 2003). The same finding was reported in feedback provision and older adults with AD were more consistent when they could access constant visual feedback (full vision condition) in the rotor-pursuit task (Dick et al., 2001). It seems that the consistency in motor planning under specific conditions is enhanced through motor learning interventions, but adaptation to environmental and task changes is less conclusive in people with cognitive impairment (van Halteren-van Tilborg et al., 2007).

Altogether, the effects of motor learning interventions in older adults with cognitive impairment in the abovementioned empirical studies (Dick et al., 2001; Dick et al., 2003; Zanetti et al., 2001) were reported in motor tasks other than walking or the nature of interventions in the review studies that used walking performance (Alexander et al., 2019; Bishnoi & Hernandez, 2020; Farhang et al., 2019; Gomaa et al., 2018; Machado et al., 2020; Zhu et al., 2021) was mixed, and it was difficult to separate the effectiveness of interventions associated with gait automaticity mechanisms (e.g. executive system plan, attention capacity, memory functions, etc.) from physical fitness components (e.g. strength, balance, flexibility, etc.). Thus, this review study only included motor learning interventions and its aim was to examine the effectiveness of such interventions on walking performance and physical functions in older adults with cognitive impairment and dementia.

## **Method**

This review study is consistent with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and was registered to PROSPERO (CRD42021260786).

### ***Study design***

We defined the study design and research question according to Participants, Interventions, Controls, and Outcomes (PICO). These were:

- Participant- older adults with cognitive impairments and dementia,
- Intervention- with a motor learning intervention,
- Control- with and without a control group,
- Outcome - gait measures and physical function.

### ***Eligibility criteria***

Studies that met the following criteria were included in this meta-analysis:

### ***Design***

- Research designs with pre-post intervention assessments with/without a control group(s) and randomised controlled trials (RCT) and non-randomised controlled trials (NRST).
- Articles published in peer-reviewed English journals between 1990- July 2021.

### ***Context***

- Study contexts were in the community, care homes or hospitals.
- Population:
- Only older adult populations (65yrs) as participants.
- Any subtype of cognitive impairment or dementia (AD, Lewy body, vascular dementia and frontotemporal).
- Cognitive impairments were not due to metabolic or neurological conditions such as Parkinson's Disease (PD) and stroke.



### ***Intervention***

- Any interventions that the main task was gait training and not other types of physical training such as balance, strength, aquatic, yoga and Tai chi.
- There was no restriction on the duration, frequency or intensity of the intervention.
- Interventions were based on the principles of motor learning (explicit learning methods such as instructions, demonstration, feedback, implicit learning methods, mental practice, attentional focus techniques such as the external-internal focus of attention, auditory cueing, visual cueing, dual-tasking, task organisation such as Contextual Interference, variability, part-whole and constraints practice.

### ***Outcomes***

One target outcome was spatiotemporal gait parameters (speed, cadence, variability).

Studies were excluded if they were 1- Case studies. 2- Exclusively reported qualitative outcomes. 3- They were abstracts from conferences. 4- Did not report data sufficiently to be included in a meta-analysis.

### ***Search strategy and study selection***

The following databases were searched: Cumulative Index to Nursing and Allied Health Literature (CINHAL), MEDLINE, Health Source: Nursing/ Academic Edition (HSNAE), SPORTDiscus, Scopus, Pubmed, Cochran Library and Allied and Complementary Medicine Database (AMED). The search strategy involved multiple steps, with a combination of two search terms used at each step (see the appendix).

Titles and abstracts were initially independently screened by two reviewers, to check for relevancy. Full texts were obtained from potentially eligible studies and were reviewed against the inclusion and exclusion criteria. Researchers hand searched citations of relevant

articles and reviews. Discrepancies in decisions were discussed amongst reviewers until consensus was achieved.

### ***Data extraction process***

Studies were organised in a Microsoft Excel worksheet according to methods, task and research outcome information. Information extracted on methods specifically included sample size, sample population, type of interventions and outcomes.

### ***Synthesis of results***

A meta-analysis was performed to calculate the pooled effect size (ES) for the outcomes based on the differences between the baseline (pre-test) and post-intervention (post-test). A random-effect model was used at a 95% confidence interval using Cochran's Q test, with  $I^2$  statistics as indices of heterogeneity. A random-effect model also accounts for differences in variability across studies by weighting each standardized effect based on its standard error. The Q statistic is the sum of squares of the weighted mean standardized effect of each study within each variable (gait outcome) divided by the overall weighted mean standardized effect for that variable.

Standardized effects indicate the magnitude of the effect of an independent variable, regardless of sample size. Standardized effects were calculated for each variable as the difference between group means (e.g. baselines and post-intervention) divided by the group pooled standard deviation. Meaningfulness was determined by Cohen's classification (Cohen, 2013): standardised effect size of less than 0.2 was considered trivial, 0.3-0.5 was considered small, 0.6-0.8 was considered moderate and above 0.8 was considered large.

The primary outcomes in this meta-analysis were gait speed, gait cadence, gait cost for speed, stride time, stride length, stride time variability, and stride length variability. The secondary outcome was dynamic balance by Timed Up and Go test (TUG). A separate meta-

analysis was carried out for each dependent variable accordingly. We narratively reported the key findings regarding the intervention design.

We only used RCT studies in meta-analysis and used both RCT and NRCT studies in systematic review.

All statistical analyses were conducted in Review Manager version 5.3.3 (Nordic Cochrane Centre). The two-tailed statistical significance level was set at  $p < 0.05$ .

### ***Study quality assessment***

The PEDro Scale (Verhagen et al., 1998) was used to assess the study quality of the RCT. The possible total score in each study ranges between 0 and 10, with higher scores representing higher study quality. The Down and Black checklist (1998) was used to assess the study quality of the NRCT. The checklist is scored between 0 and 32, with higher scores representing higher study quality. Two reviewers screened the full texts and assessed their quality independently and an agreed score was reported. Discrepancies in quality rating were resolved by discussion. Quality ratings were used to describe and contextualise findings but were not used to exclude studies.

The GRADE approach (GRADE Working Group, 2004) was used to evaluate the certainty of evidence based on 4 ranks (very low, low, moderate, and high) for each outcome in 5 domains (risk of bias, imprecision, inconsistency, indirectness, and publication bias).

## **Results**

### ***Search results***

The searching date started from June 2021 and completed in July 2021. The search results yielded 859 articles with additional 20 articles from the review studies. After removing duplicates, 849 articles were selected. After reading the titles, 796 articles were excluded according to the inclusion and exclusion criteria. The abstracts of 53 articles were reviewed,

and 33 articles were included. Studies with mixed intervention such as fitness factors, only for protocol design and without results, no specific intervention to the motor learning, lack of gait analysis or experimental design, the populations of adults under 65 years or with neurological conditions (e.g. PD, stroke) and literature review studies were excluded after retrieving the full text (n=23). Finally, six articles reported data sufficiently for meta-analysis and 11 articles for systematic review (see Figure 1).

Insert Figure 1 here

### ***Quality assessment***

The mean PEDro score in RCT studies was 7.3 ( $\pm 0.51$ ). The main methodological issues in the selected studies were blinding the subjects, the therapist, and the assessor (criteria 5, 6 and 7). See Table 1 for quality assessment scores of included studies. In the NRCT studies, the mean score was 18 ( $\pm 0.7$ ). The main methodological issues were the lack of any report on confounding variables and adverse effects.

### ***Synthesis of studies***

Important information regarding the selected studies such as participants, motor learning method, type of intervention, outcomes and key findings is presented in Table 1. We qualitatively reported the studies in the following sections.

Insert Table 1 here

### ***Motor learning interventions***

The types of gait intervention in the selected studies were auditory cueing with music or metronome (Y.-L. Chen & Pei, 2018; Clair & O'Konski, 2006; Domínguez-Chávez, Murrock, Guerrero, & Salazar-González, 2019; Wittwer, Webster, & Hill, 2013; Wittwer, Winbolt, & Morris, 2020), dual-tasking (Lemke et al., 2019; Orcioli-Silva et al., 2018), functional mobility (Ries et al., 2010; Toots et al., 2017) and explicit learning methods such as

observation and feedback (Rojasavastera, Bovonsunthonchai, Hiengkaew, & Senanarong, 2020; Schwenk et al., 2016). The dose of interventions was varied in terms of duration and length. In the auditory cueing method, the intervention length was 1 day (Wittwer et al., 2013), 1 month (Wittwer et al., 2020), 2 months (Y.-L. Chen & Pei, 2018; Clair & O'Konski, 2006) and 3 months (Domínguez-Chávez et al., 2019). The functional mobility had durations between 2 (Ries et al., 2010) and 4 months (Toots et al., 2017). The intervention period in dual-tasking was 2.5 months (Lemke et al., 2019). The explicit learning interventions lasted between 1 month (Schwenk et al., 2016) and 1.5 months (Rojasavastera et al., 2020). Most of the studies were completed 2-3 times per week and usually lasted 45-90min.

### *Gait performance changes*

#### Gait speed

The overall effect of the intervention on gait speed was significant and the participants walked faster after the intervention ( $ES_{\text{mean}} = -0.46$ ;  $CI = -0.88$ :-0.05;  $Z = 2.17$ ;  $p < 0.05$ ). Cochran  $Q^2$  results showed a moderate heterogeneity ( $Q^2 = 14.81$ ,  $I^2 = 66\%$ ) among the studies. The improved gait speed was reported in selected studies through auditory cueing (Domínguez-Chávez et al., 2019; Wittwer et al., 2020), dual-tasking (Lemke et al., 2019; Orcioli-Silva et al., 2018), functional mobility (Ries et al., 2010) and explicit learning (Rojasavastera et al., 2020). Because of moderate inconsistency and risk of bias in some studies, the certainty of evidence in gait speed was “low”.

#### Gait cadence

Gait cadence was higher after the intervention ( $ES_{\text{mean}} = -0.83$ ;  $CI = -1.18$ :-0.47;  $Z = 4.61$ ;  $p < 0.05$ ). Cochran  $Q^2$  results showed moderate heterogeneity ( $Q^2 = 0.5$ ,  $I^2 = 0\%$ ) among the studies. The gait cadence only increased through dual-tasking (Lemke et al., 2019; Orcioli-Silva et al., 2018) and not by auditory cueing interventions (Chen & Pei, 2018; Clair &

O'Konski, 2006; Domínguez-Chávez et al., 2019; Wittwer et al., 2013). The certainty of evidence in cadence was “moderate” due to low risk of bias, consistency and lack of publications bias and methodological limitations in the studies.

#### Gait cognitive cost

Gait cognitive cost was decreased after the intervention ( $ES_{\text{mean}} = 0.55$ ;  $CI = 0.25:0.85$ ;  $Z = 3.6$ ;  $p < 0.05$ ). Cochran  $Q^2$  results showed a low heterogeneity ( $Q^2 = 7.09$ ,  $I^2 = 72\%$ ) among the studies. The cost of gait performance was decreased after the dual-tasking intervention (Lemke et al., 2019), whereas the auditory cueing was not effective (Chen & Pei, 2018). Because of moderate inconsistency and risk of bias in some studies, the certainty of evidence in gait cognitive cost was “low”.

#### Stride time

None of the studies that measured stride time has reported any change after the intervention (Wittwer et al., 2013; Wittwer et al., 2020). The certainty of evidence in stride was “low” due to low risk of bias and inconsistency.

#### Stride length

Stride length was increased after the intervention ( $ES_{\text{mean}} = -0.33$ ;  $CI = -0.64:-0.02$ ;  $Z = 2.08$ ;  $p < 0.05$ ). Cochran  $Q^2$  results showed a low heterogeneity ( $Q^2 = 3.27$ ,  $I^2 = 8\%$ ) among the studies. Dominiguez et al (Domínguez-Chávez et al., 2019) and Wittwer et al (Wittwer et al., 2020) reported an increased stride length after auditory cueing and Lemke et al (Lemke et al., 2019) reported an increased stride length after the dual-tasking intervention. The certainty of evidence in stride length was “moderate” due to low risk of bias, consistency and lack of publications bias and methodological limitations in the studies.

#### Stride time variability

There was not any significant effect of the intervention on stride time variability ( $ES_{\text{mean}} = 0.13$ ;  $CI = -0.44:0.48$ ;  $Z = 0.44$ ;  $p > 0.05$ ). None of the studies (Rojasavastera et al., 2020; Schwenk et al., 2016; Wittwer et al., 2013; Wittwer et al., 2020) that measured stride time variability has reported any change after the intervention (auditory cueing and explicit learning methods). The certainty of evidence in stride length was “moderate” due to low risk of bias, consistency and lack of publications bias and methodological limitations in the studies.

#### Stride length variability

Only Wittwer et al (Wittwer et al., 2013) reported an increased stride length variability after the auditory cueing intervention. The certainty of evidence in stride length variability was “low”.

Insert Figure 2 here

#### *Physical function changes*

##### TUG test

There was not any significant effect of the intervention on TUG score ( $ES_{\text{mean}} = 0.1$ ;  $CI = -0.67:0.87$ ;  $Z = 0.25$ ;  $p > 0.05$ ). Ries et al (Ries et al., 2010) reported an increased TUG score after the functional mobility intervention. No change was reported after the auditory cueing intervention (Chen & Pei, 2018). The certainty of evidence in TUG test was “moderate” due to low risk of bias, consistency and lack of publications bias and methodological limitations in the studies.

The forest plots of the meta-analysis on gait performance measures are presented in Figure 2.

## Discussion

This study aimed to review and examine the effects of motor learning interventions that were used to improve gait and physical functions in older adults with cognitive impairment and dementia. The findings of the meta-analysis showed that the overall effects of different types of motor learning intervention on some gait parameters such as speed, cadence, cognitive cost, stride length and stride length variability were low to moderate and there was no effect on physical functions. The results of the systematic review showed that mainly gait performance was improved following dual-tasking and auditory cueing, whereas functional mobility and explicit learning method were effective on physical functions. Only gait speed was improved by all types of intervention. The underlying mechanisms and some considerations on the effects of motor learning interventions on gait and physical functions are explained in the following sections.

Dual-tasking had a significant role in increasing gait speed, cadence, stride length and decreasing gait cognitive cost (Lemke et al., 2019). Despite the strong evidence on the role of dual-task walking as an assessment tool to diagnose cognitive impairment in older adults (Bishnoi & Hernandez, 2020), there was not enough study on its effectiveness as an intervention method to improve gait performance or physical functions. Few studies have reported the positive effects of dual-task training on gait and balance in older adults with balance impairment, stroke, and PD (Canning, Ada, & Woodhouse, 2008; Silsupadol et al., 2009; Yang, Wang, Chen, & Kao, 2007). Schwenk et al (Schwenk, Zieschang, Oster, & Hauer, 2010) used the cognitive dual-task as a part of the multicomponent intervention in older adults with dementia. The dual-task walking only practised 15 minutes out of 2h practice sessions and twice a week. They showed an improved gait speed and a reduced gait cognitive cost after 3 months intervention period.



The cognitive-motor interference during walking could be explained according to cognitive psychology and ecological psychology theories. The most common explanation for interference between primary and secondary tasks is the “overloading” of cognitive processes such as working memory, which has limited capacity (Keele, 1973). In overloading, there is a competition between the required tasks to use the available capacity (Shaffer, 1971) and cross talk between tasks is observed as performance decrement (Koch, 2009). An alternative explanation is action selection (Neumann & Sanders, 1996). According to Neumann’s theory, selection rather than attention capacity is the most fundamental process of attention and underlies the interference between two tasks. This view has significant implications in terms of ecological aspects of tasks. If a particular action is selected due to its priority and importance for the performer, other actions may be prevented from occurring (R. Schmidt & Lee, 2011). Plummer, Grewal, Najafi, and Ballard (2015) showed that dual-task effects are more reliable when participants are given specific instructions about how to prioritise their attention. For example, for an older adult with age-related changes in sensory and motor systems, prevention of a fall during stair descent is more salient than a possible dual-task (e.g., the accuracy of speech while speaking on a phone). Emphasis on the goal of motor activity and selecting the most important task in daily multitask situations is also described in the ecological constraint approach. The ecological model of multi-tasking comprises selection, optimization, and compensation (Baltes & Baltes, 1990). In this model, selection relates to goals or outcomes such as the maintenance of postural stability, optimisation relates to goal-relevant means such as practice, and compensation involves the use of alternative means to maintain performance (Charness, 1991), for example, modifying the gait speed while descending stairs and paying more attention to the contents of the phone call.

The auditory cues, as forms of metronome and music, have been reported as effective interventions to increase gait speed and stride length (Domínguez-Chávez et al., 2019;

Wittwer et al., 2020). Changes in walking performance due to auditory cues could be related to neural pathways between motor and auditory regions such as supplementary motor areas, the cerebellum, the basal ganglia and premotor cortex (J. Chen, Penhune, & Zatorre, 2009; Michael Thaut, 2013). More specifically, the improvements in gait speed and stride length might be attributed to the ability of auditory cues to access the auditory-premotor circuit (J. Chen et al., 2009; Michael Thaut, 2013), enhanced synchronisation between movements and sounds (Tierney & Kraus, 2013) or plasticity in auditory-motor networks that persists even after the end of intervention as it shown in people with stroke and PD (Rochester et al., 2010; MH Thaut et al., 2007). Another possible explanation is cognitive reserve instead of cognitive competition when the cues act as a simple task (without instructions) rather than a secondary task (explicit instructions to consciously attend to the cues) that could increase gait automaticity and reduce the complexity in executive functions (Wittwer et al., 2013).

However, the dose and length of intervention are important factors for long-term changes in mild to moderate dementia severity (van Halteren-van Tilborg et al., 2007), even one week home practice was effective to improve gait speed in older adults with AD (Wittwer et al., 2013). The increased stride length variability in this study and specifically following auditory cueing might be explained as a by-product of the changes in gait speed (Webster, Merory, & Wittwer, 2006) or as a part of the adaptation mechanism in the executive systems. In fact, they might prioritise the speed change to subtle changes in other spatiotemporal gait measures due to deficits in executive systems. The lack of change in time variability might be regarded as insufficient intervention dose and duration because the gait variability requires higher-order cortical functions in planning, navigation and sensorimotor integration that all contribute to gait automaticity (Tian et al., 2017).

Functional mobility and explicit learning methods partially resulted in significant changes in gait speed and physical functions (Ries et al., 2010; Rojasavastera et al., 2020;

Schwenk et al., 2016). The functional mobility interventions that have been used in people with dementia mainly focused on balance, stability and gait functions through changes in different tasks constraints (e.g. obstacles, direction change, etc.). These types of task constraints might help older adults to improve anticipation and planning due to exposure to different situations (Ries et al., 2010). For example, the TUG test and gait velocity both are tasks that require spatial awareness and planning and practising different versions of such tasks could enhance the executive system functions and gait adaptations. The explicit learning methods such as observation and feedback provision also have involvements in action execution and working memory through feedback-loop systems in the cerebellum (Johnson, Belyk, Schwartze, Pinheiro, & Kotz, 2019) and mirror neurons (Sarasso, Gemma, Agosta, Filippi, & Gatti, 2015) that all sensitive to declines in patients with dementia (Scherder, Eggermont, Visscher, Scheltens, & Swaab, 2011). Hence, activating these regions through motor learning interventions could be beneficial for demented older adults.

Despite the positive and overall effect of the intervention on gait performance, the results should be interpreted cautiously due to some personal and task constraints that might affect the effectiveness of the intervention. We rate the quality of evidence low to moderate based on the GRADE certainty rating for different reasons. First, the differences in types of motor learning intervention in calculating pooled effect size had low to moderate heterogeneity in this study that might be originated from differences in the intervention dose, length and measurement issues. It seems this area of research requires more robust studies such as RCT studies focusing on underlying motor learning principles of gait declines in older adults with dementia. Second, quality analysis of this review may be compromised by lack of information on several criteria, for example, on methods used to control the pure effect of intervention. Therefore, researchers must ensure high methodological quality trials and provide all the information necessary for study quality/reporting analysis, and describe

statistical data, in order to guide strong recommendations of motor learning interventions for individuals diagnosed with dementia.

This study has some implications for clinical practitioners who work with older adults with cognitive impairment and dementia. The motor learning interventions are likely to be safe and feasible exercise modalities that emphasise the cognitive and motor systems and are appropriate for dementia-related gait declines (e.g., speed and cognitive cost). Practicing this type of intervention as a part of a weekly exercise routine could help them to improve motor and cognitive functions along with physical and mobility factors. Older adults with and without cognitive impairment have to negotiate with the environmental constraints and adopt a safe strategy in walking. Using motor learning interventions that are integrated within activities of daily living can stimulate perceptual-motor skills such as anticipation, prediction, awareness and pace control that would be beneficial for preventing cognitive and motor declines.

The main limitation of this study was that there were a limited number of RCT studies that could be included in the meta-analyses, and therefore our interpretations were supplemented by NRCT studies. The benefits of motor learning interventions on gait and functional activities in this population should be studied through a more robust methodology. In addition, we did not investigate the severity of cognitive impairments on the effectiveness of interventions. Future research also should consider the impact of condition severity and baseline frailty on intervention efficacy, whilst being vigilant about whether motor learning interventions increase the risk of adverse events (which was outside the scope of this research).

In conclusion, this study provides evidence in support of motor learning interventions as a standalone modality in the rehabilitation of older adults with cognitive impairment and dementia. The findings of this study could be regarded as an impetus for future studies to

direct more attention to the association between cognition-action integration as a part of gait retraining interventions. Practitioners should consider adopting interventions that focus on motor learning principles as means of rehabilitation for older adults with cognitive impairment and dementia.

### ***Declaration of interest***

The authors report no declarations of interest.

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## Appendix

The search steps:

step 1: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults"

step 2: "walking training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults"

step 3: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "feedback"

step 4: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "implicit learning",

step 5: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "focus of attention"

step 6: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "cueing"

step 7: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "music"

step 8: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "constraints",

step 9: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "imagery training"

step 10: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "split belt treadmill"

step 11: "gait training" AND "dementia/Alzheimer's Disease/cognitive impairment" AND "older adults" AND "perturbation".

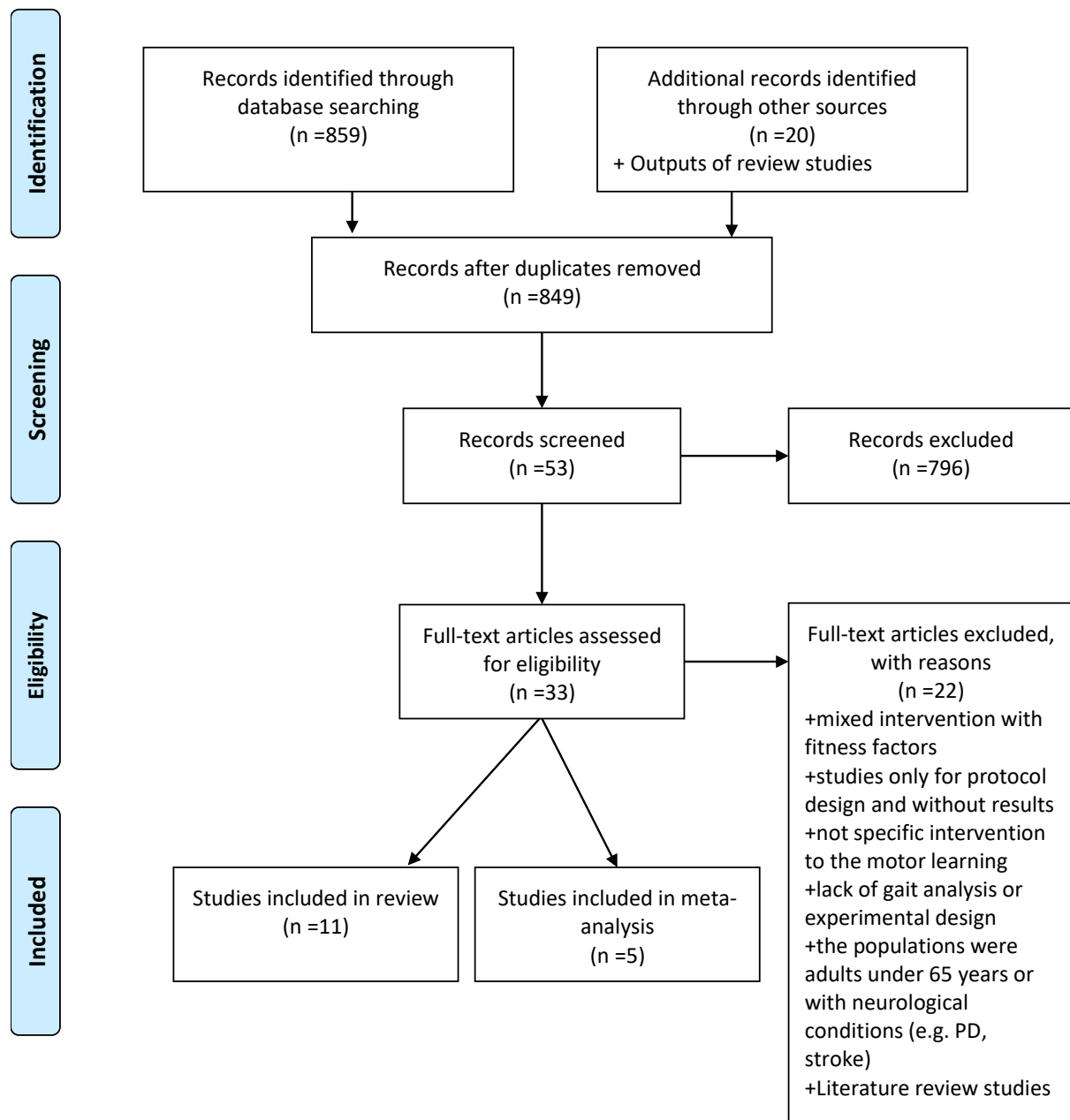
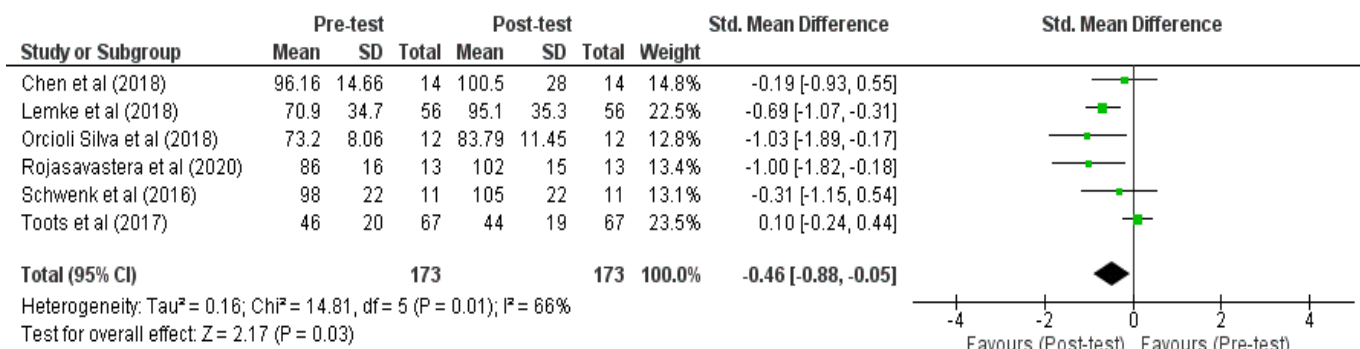
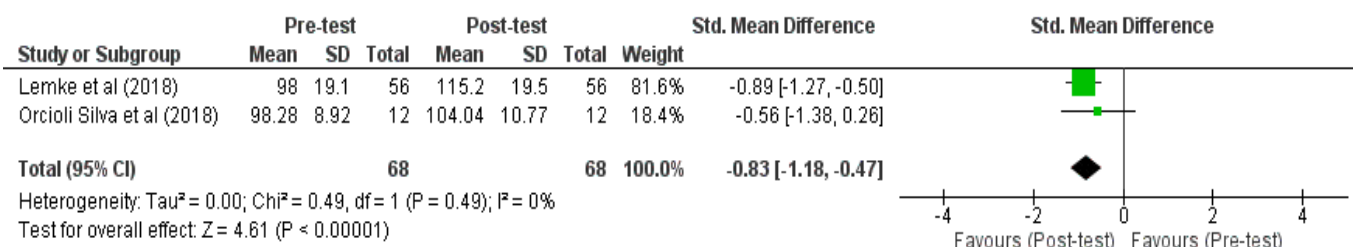


Figure 1- PRISMA flow diagram for gait interventions in older adults with dementia

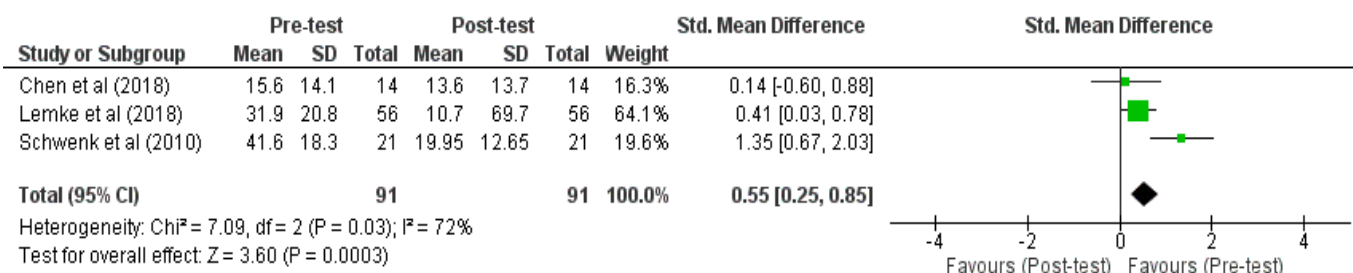
## Gait speed



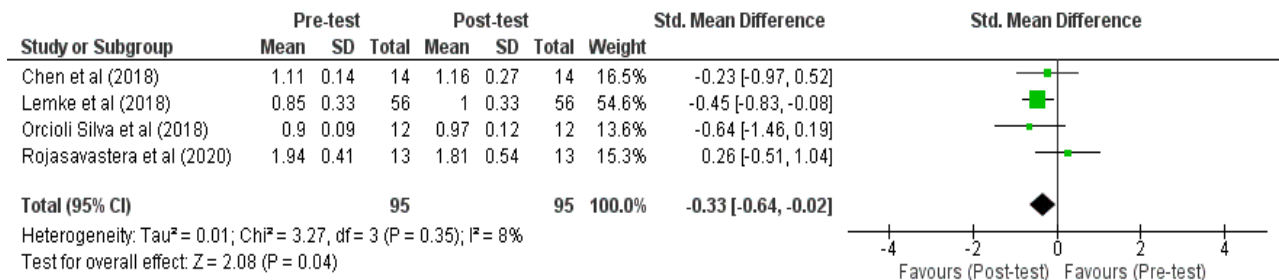
## Gait Cadence



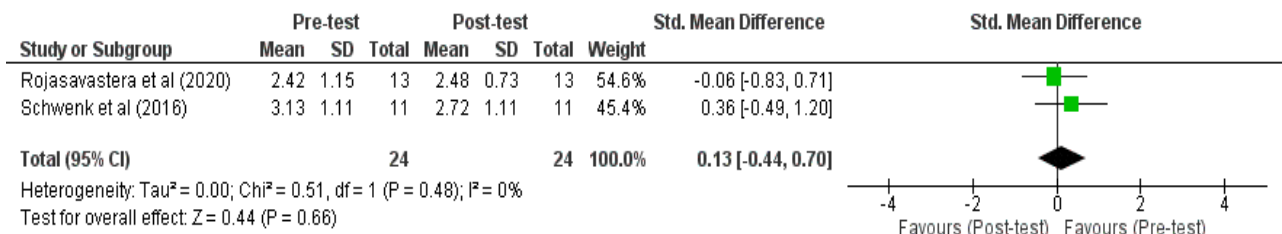
## Gait speed Cognitive Cost



## Stride Length



## Stride Time Variability



## TUG Test

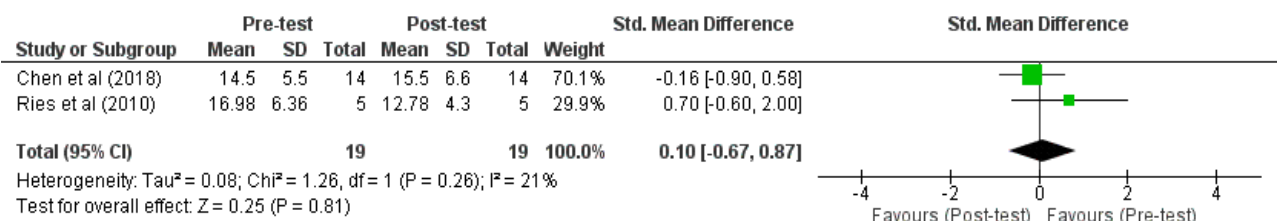


Figure 2- Forest plots of gait intervention effects on different gait parameters and physical function

**Table 1- Main characteristics of studies such as participants, the type of intervention, main outcomes and key findings.**

Study	Participants	Motor learning technique	Type of intervention	Selected outcomes	Quality Score (PEDro/Modified Downs and Black)	Key findings
<b>1-Chen et al (2018)</b> <b>Taiwan</b>	14 males and females (77.3±9.4yrs) in intervention and 15 males and females (77.3±10yrs) in control with mild to moderate dementia (Alzheimer's Disease, Vascular Dementia)	Auditory cueing	Music dual-task training for 8 weeks/60min per session. The participants were asked to respond to obstacles (visual stimuli) and engage in conversation (auditory stimuli) while walking. The protocol included a musical task and a walking task. The musical task comprised two types of activities such as singing and playing simple percussive musical instruments.	Gait speed, stride length, cadence, dual-task cost, fall efficacy, Timed Up and Go Test (TUG)	PEDro=7	No significant change was reported in any primary and secondary outcome after the intervention.

<b>2-Clair et al (2006)</b>  <b>United States</b>	4 males and 24 females (from 70 to 92 years old) diagnosed with dementia in late stage who had Locomotion Functional Independence Measure (FIM) ratings of 1, total assistance required	Auditory cueing	All participants enrolled in a restorative ambulation program which was implemented under 3 conditions: Rhythmic auditory stimulation in which metronomic beats were imbedded in music, rhythmic auditory stimulation which consisted of metronomic beats without music, and no auditory stimulus. The participants completed 9 sessions (2 sessions per week).	Gait speed, stride length, cadence	19	No statistically significant difference were found after the intervention.
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<b>3-Dominiguez et al (2019) Mexico</b>	16 older adults aged 60 and over with mild cognitive impairment	Auditory cueing	The intervention was comprised activities based on the expression of rhythm, melody, harmony and qualities of sound (timbre, intensity and height) through body movements and its sessions were held for one hour, three times per week for 12 weeks.	Gait speed, stride length, cadence	18	Significant effects were found in gait velocity, right stride length, and left stride length after the intervention.
<b>4-Lemke et al (2019) Germany</b>	105 patients with mild-to moderate dementia. 39 females and 17 males in intervention group (82.7±6.2yrs) and 37 females and 12 males in control group (82.6±5.8yrs)	Dual tasking	The intervention group underwent a specific Dual Task training (“walking and counting”) for 10 weeks (1.5 h twice a week) while the control group performed unspecific low-intensity exercise (1 h twice a week)	Gait speed, stride length, cadence, dual-task cost	PEDro=8	The intervention group significantly improved dual task performances in the trained condition for



						absolute motor and cognitive performance and for motor, cognitive, and combined motor-cognitive dual task costs compared to the control group.
<b>5-Orcilio Silva et al (2018)</b> <b>Brazil</b>	30 patients with Alzheimer's disease. 15 participants in the intervention group (79.17±7.6yrs) and 15 participants in the control group (77±5.5yrs)	Dual tasking and functional mobility	The intervention group underwent a specific cognitive and motor tasks (Dual Task, attention and agility/balance) for 16 weeks (1 h/ 3 times a week) while the control group did not take part in any physical activity	Stride length, stride time, cadence	PEDro=7	The intervention group significantly improved stride length, stride time and cadence.

<b>6-Ries et al (2010)</b>  <b>United States</b>	4 females and 1 male diagnosed with Alzheimer Disease or probable AD (from 81 to 93 years old)	Functional mobility	All participants engaged in a functional dynamic balance exercise program in two 45- minute sessions each week for 8 weeks. Balance activities were functional and concrete, and the intervention was organized into constant, blocked and massed practice.	Gait speed, Timed Up and Go Test (TUG)	18	Four participants improved their performance on the TUG. Gait Speed increased in three participants after intervention.
<b>7-Rojasavastera et al (2020)</b>  <b>Thailand</b>	33 participants with amnesic mild cognitive impairment allocated in action observation with gait training (67.64±4.64 yrs; 2 males, 9 females), gait training (67.50±5.60 yrs; 3 males, 8 females) , and	Observation	The action observation with gait training group watched a video of normal gait movement, while the gait training group watched an abstract picture and the control group received no training program with the same total duration of 65 min	Gait speed, stride length, stride time variability	PEDro=8	The action observation with gait training group and the gait training group had significant improvements in gait speeds and

	control groups (65.71±2.45 yrs; 3 males, 8 females).		for 12 sessions (2-3 sessions per week).			not in other variables.
<b>8-Schwenk et al (2016)</b> <b>United States</b>	Participants were patients with amnesic mild cognitive impairment (mean age 78.2 years) and were randomized to intervention group (n= 12) and control group (n= 10).	Feedback	The intervention group underwent balance training (4 weeks, twice a week) including weight shifting and virtual obstacle crossing. Real-time visual/audio lower-extremity motion feedback was provided using wearable sensors. The control group received no training.	Gait speed, stride time variability, fall efficacy	PEDro=7	Sway (eyes open) and fear of falling were reduced in intervention group compared to control group. Changes in other measures were not significant.

<b>9-Toots et al (2017)</b>  <b>Sweden</b>	141 women and 45 men (mean age 85 years) with dementia divided into the experiment group (n=93) and the control group (n=93). 145 (78%) habitually used walking aids.	Functional mobility	Participants were randomized to the high-intensity functional exercise program (walking, dual-tasking, obstacle crossing, etc.) or a seated attention control activity which lasted 4 months (40 sessions in total) and consisted of five 45- minute sessions per 2-week period	Gait speed	PEDro=7	No between- group effect in either gait speed test at 4 or 7 months was reported. In interaction analyses exercise effects differed significantly between participants who walked unsupported compared with when walking aids or minimum support was used.
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<b>10-Wittwer et al</b>  <b>(2013)</b>  <b>Australia</b>	30 participants (80±6y)  diagnosis of probable AD  and ability to walk 100m.	Auditory cueing	Participants walked 4 times  over an electronic walkway  synchronizing to (1) rhythmic  music and (2) a metronome  set at individual mean  baseline comfortable speed  cadence. The participants  completed 4 walking trials for  baseline and 4 trials per  condition at the same  session.	Gait speed, stride length,  cadence, stride time,  stride time variability,  stride length variability	17	Gait velocity  decreased with  both music and  metronome cues  compared with  baseline,  primarily because  of significant  decreases in  stride length with  both cue types.  This was coupled  with increased  stride length  variability  compared with  baseline with  both cue types.
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						Temporal variability was unchanged. No change in cadence.
<b>11-Wittwer et al (2020)</b> <b>Australia</b>	11 (77.0 years; 3 females and 8 males) community-dwelling adults living with Alzheimer's Disease.	Auditory cueing	The intervention consisted of eight progressively modified 45-min music gait training sessions delivered during home visits over 4 weeks (2 sessions per week).	Gait speed, stride length, stride time, stride time variability, stride length variability	18	Tests revealed statistically significant increases in gait speed following the intervention. Stride length also improved. There was no significant change in gait variability and stride time.