Journal of Physiotherapy 68 (2022) 26–36

Journal of
PHYSIOTHERAPY

journal homepage: www.elsevier.com/locate/jphys

Research

Degree and pattern of dual-task interference during walking vary with component tasks in people after stroke: a systematic review

Charlotte Sau-Lan Tsang [a], Shuting Wang [b], Tiev Miller [a], Marco Yiu-Chung Pang [a]

[a] Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong; [b] School of Biomedical Sciences, The Chinese University of Hong Kong, Hong Kong

KEY WORDS

Dual-task interference
Cognitive-motor interference
Stroke
Systematic review
Meta-analysis

ABSTRACT

Questions: What are the degree and pattern of dual-task interference during walking in people after stroke? How do these vary with disease chronicity and different component tasks in people after stroke? How does dual-task interference differ between people after stroke and people without stroke? **Design**: Systematic review with meta-analysis of studies reporting gait-related dual-task interference. **Participants**: People after stroke and people without stroke. **Outcome measures**: Measures of walking and secondary (cognitive or manual) task performance under dual-task conditions relative to those under single-task conditions. **Results**: Seventy-six studies (2,425 people after stroke and 492 people without stroke) were included. Manual and mental tracking tasks imposed the greatest dual-task interference on gait speed, although there was substantial uncertainty in these estimates. Among mental tracking tasks, the apparently least-complex task (serial 1 subtractions) induced the greatest dual-task interference (−0.17 m/s, 95% CI −0.24 to −0.10) on gait speed, although there was substantial uncertainty in these estimates. Mutual interference (decrement in both walking and secondary component task performances during dual-tasking) was the most common dual-task interference pattern. The results of the sensitivity analyses for studies involving people with chronic stroke were similar to the results of the primary analyses. The amount of dual-task interference from a mental tracking or manual task during walking was similar between people with or without stroke. **Conclusions**: The degree and pattern of dual-task interference vary with the choice of component tasks. When evaluating limitations to functional mobility during dual-tasking conditions and in planning interventions accordingly, clinicians should select dual-task assessments that correspond to the daily habits and physical demands of people after stroke. **Registration**: CRD42017059004. **[Tsang CS-L, Wang S, Miller T, Pang MY-C (2022) Degree and pattern of dual-task interference during walking vary with component tasks in people after stroke: a systematic review. *Journal of Physiotherapy* 68:26–36]**

Introduction

Scenarios requiring an ability to perform dual-task walking, such as attending to traffic and memorising a shopping list while walking, are frequently encountered in daily life. In comparison to conditions where tasks are performed separately (ie, single-task conditions), a degradation in the performance of one or both component tasks may occur when performed concurrently;[1,2] this is commonly referred to as dual-task interference (DTI). A number of theories, which are not all mutually exclusive, have been proposed to explain the DTI phenomenon.

Capacity sharing theory: The capacity sharing theory assumes a finite processing and attention capacity in people (resources-based).[1] This capacity and the total amount of attention employed at any given time is flexibly shared among all involved tasks, resulting in less capacity and attention for each component task.[1] When the capacity and demand of component tasks do not match, task performance either deteriorates or fails completely.[1]

Bottleneck or task switching theory: This theory assumes a stage of internal processing that can only operate on one stimulus or response at a time (operation-based).[1] When two stimuli are presented at the same time, only one is perceived, whereas the other is completely ignored. If both are perceived, the responses are often elicited in succession rather than concurrently, causing a bottleneck delay, thereby impairing the perception of or response to either or both tasks.[1,2]

Multiple resource capacity theory: Multiple resource capacity simulates a hybrid of the capacity sharing and bottleneck models. Instead of one overall flexible pool of attentional resources or one single operational channel, parallel or relatively independent processing resources are assumed. Each of these resources has its own capacity limitations, which are allocated between tasks. Performance deterioration happens when tasks compete for the same resource. The resultant degree of DTI depends on the extent to which tasks share independent resources.[3,4]

Cross talk theory: Cross talk refers to a transference of energy from one communication channel to another.[5] The cross talk model focuses on the content of the information being processed (content-oriented). This may include the sensory input being presented, responses being produced or momentary thoughts.[2] When similar inputs are involved, the same set of processing machinery may be shared for both, making

https://doi.org/10.1016/j.jphys.2021.12.009
1836-9553/

it easier to perform two tasks simultaneously.[2] This results in a dual-task facilitation (an improvement in the performance of either or both component tasks relative to single-task performance).[6] However, DTI may occur when there is an outcome conflict, in which the production of outputs, throughputs or side effects by one task hinders processing of another.[2]

DTI not only has an impact on community ambulation,[7,8] but also on other activities of daily living,[9,10] functional independence,[9,11] fall proclivity,[12–15] and community participation;[16] all of these factors ultimately affect quality of life.[17,18] Over the past decade, the volume of research devoted to investigating the effects of DTI on walking among people with brain damage, including stroke,[6,9,10,12,19–27] has grown. However, previous systematic reviews have focused on either healthy participants[28–30] or participants with a mix of different neurological diseases.[31,32] Populations vary in how DTI influences cognitive function,[33–35] attentional demands during walking[36–40] and dual-task walking ability.[41–44] The degree and pattern of DTI have also been shown to differ with component task type[9,10,23,28–30,45] and complexity[21,45] among people after stroke, but not in people with Parkinson's disease.[42] A recent systematic review of 20 studies assessed dual-task ability during concurrent locomotor and cognitive tasks in adults after stroke and reported that a mutual interference pattern was consistently observed among studies involving more challenging walking tasks (eg, obstacle-crossing).[46] Mutual interference was also more frequent among people after stroke than healthy controls. However, no meta-analyses quantifying the effects of DTI on different gait parameters or secondary task performance were undertaken in that review. Their findings were also limited to dual-task conditions involving the performance of a walking task in conjunction with a cognitive task. The effect of DTI on gait during attention-demanding manual tasks was not examined. According to the aforementioned multiple resource capacity theory, adding a manual task (which involves recruitment of both motor and cognitive systems) may induce greater DTI than adding a cognitive task (which mainly involves the cognitive system) during walking. This in turn may have a direct influence on risk aversion and walking safety. The way in which the degree and pattern of DTI during walking varies according to task domain and stage of recovery (ie, chronicity) in individuals after stroke remains unknown. A systematic review and meta-analysis consolidating the mounting, but fragmented, evidence on the phenomenon of DTI during walking among people after stroke at different stages of recovery is currently lacking in the available literature.

Therefore, the research questions for this systematic review were:

1. What are the degree and pattern of dual-task interference during walking in people after stroke?
2. How do these vary with disease chronicity and different component tasks in people after stroke?
3. How does dual-task interference differ between people after stroke and people without stroke?

Methods

This systematic review and meta-analysis is reported in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[47]

Data sources and searches

A literature search of electronic databases – including CINAHL, Cochrane Library, EMBASE, MEDLINE (1946+), PsycINFO (1806+) and PubMed – and a forward search for additional articles on electronic databases, including Scopus and Web of Science, were performed with the last search conducted on 23 April 2021. No restrictions on study design were imposed. We extracted only baseline results for intervention or cohort studies. Search keywords were based on population (stroke) and constructs of interests (DTI during walking) (Appendix 1 on the eAddenda). The reference lists of eligible studies and review articles were manually screened to identify additional articles for inclusion.

Study selection

All results were exported to reference management software[a] for screening and duplicate removal. Two independent reviewers assessed each title, abstract and full-text against the inclusion criteria (Box 1) and exclusion criteria: reports published as conference proceedings, book chapters and theses. In the event of discrepancies between reviewers, the principal investigator was consulted.

Data extraction and quality assessment

Two reviewers extracted information regarding study design, inclusion and exclusion criteria, sample size, subject characteristics, walking and component task characteristics, task prioritisation, outcome measures, testing procedures and reported results. Graphically presented data were extracted using a digital plotting tool[b].

The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies developed by the National Institute of Health was used to assess the methodological quality of included studies.[48] Two reviewers independently evaluated each eligible article. If no consensus was reached, the opinion of the principal investigator was sought. To provide a more objective appraisal of overall quality, percentages for the total number of items rated 'yes' were calculated. Overall ratings of 'good', 'moderate' and 'poor' were determined based on resultant percentages $\geq$ 75%, 50 to 74% and $<$ 50%, respectively.[49]

Data synthesis and analysis

To facilitate comparisons across studies and delineate the effect of different component task domains on dual-task gait performance, included studies were categorised according to the secondary tasks involved.[28] DTI patterns were classified according to the categorisation model proposed by Plummer et al.[6] The nine possible DTI patterns are depicted in Table 1.

To estimate the overall effect of DTI on gait and secondary task performance, primary meta-analyses and subsequent sensitivity analyses based on the stage of stroke recovery were conducted for groups of three or more studies reporting the same outcome. For groups of three or more studies that reported the same outcome and included both stroke and age-matched control groups, additional meta-analyses were conducted to compare the effect of DTI on gait and secondary task performance between people with and without a history of stroke. For studies that reported more than one dataset per participant group for the same task category, one task was randomly selected for inclusion in the meta-analysis in order to avoid a unit-of-analysis error.[50] When these studies were included in more than one

Box 1. Inclusion criteria.

Design
- Experimental, observational or exploratory study
- Published in English

Participants
- Adults with stroke

Intervention
- Not applicable

Outcome measures
- Walking performance

Comparisons
- Walking performance under dual-task condition versus without the dual-task condition
- Dual-task interference in people with stroke versus people without stroke

Table 1
Nine dual-task interference patterns.

		Cognitive/manual performance		
		No change	Improved	Worsened
Mobility performance	No change	No interference	Cognitive/manual facilitation	Cognitive/manual interference
	Improved	Mobility facilitation	Mutual facilitation	Mobility priority trade-off
	Worsened	Mobility interference	Cognitive/manual priority trade-off	Mutual interference

meta-analysis (ie, for comparing the effect of DTI among different task categories, between different tasks within the same task category, and/or between the stroke and age-matched control groups), the same randomly selected tasks were carried forward in subsequent meta-analyses. For each study, the raw mean difference (MD)[51–53] was calculated for each outcome of interest. A random-effects model of the generic inverse variance method was used. Heterogeneity between studies was analysed with the I^2 statistic.[54] Forest plots indicating effect sizes with 95% CI, heterogeneity and corresponding *p*-values were generated using RevMan software[c].[53] For analyses with significant overall effects, publication bias was assessed using Egger's regression tests.[55] Further analyses with Duval and Tweedie's trim and fill and the classic fail-safe N methods were also conducted to assess the effect of potential publication bias on the certainty of evidence.[56] These analyses were performed using commercial software[d].[57]

Results

Flow of studies through the review

A PRISMA flow chart summarising the screening process is provided in Figure 1. Electronic searches identified 15,824 unique records. After screening and assessment, 76 of 133 shortlisted articles involving a total of 492 healthy controls and 2,425 participants with stroke met the criteria for inclusion (see Table 2 on the eAddenda). Among the 76 studies included in the systematic review, 50 provided sufficient data for conducting meta-analyses (see Table 3 on the eAddenda). Twenty-seven of the 50 studies involved only people with chronic stroke and were included in subsequent sensitivity analyses (see Table 2 on the eAddenda).

Characteristics of the participants

The mean age of participants in the included studies ranged from 49 to 77 years. Forty-seven of 76 (62%) studies included only people ≥ 6 months after stroke onset, one study included only people within 72 hours of stroke onset,[58] and six studies recruited people within 6 months of stroke onset.[14,59–63] The remaining studies included a mix of people in different stages of stroke recovery.

Characteristics of the dual-task testing protocols

Twenty-two studies (29%) involved more than one secondary task in their dual-task assessment protocols. Among these studies, five reported more than one dataset (ie, dual-task assessment) for the same group of participants within a single task category.[10,27,63–66] One study reported dual-task walking performance for a manual task involving the more-affected and the less-affected hands of the same group of participants.[64] Hence, 24 datasets (14%) were removed from the meta-analyses to avoid unit-of-analysis errors. Mental tracking was the most adopted secondary task category. Gait speed was the most used measure of walking performance, while secondary task measures were diverse among the studies. Participants were either instructed to perform both tasks equally well or given no explicit prioritisation instructions (see Table 3 on the eAddenda).

Quality assessment of included studies

All included studies stated their objectives and inclusion/exclusion criteria. The diagnosis of stroke and outcome measures were also clearly defined. Other criteria were achieved by fewer studies: 45% provided sample size justification, power description or variance and effect estimates; 33% adjusted for potential confounding variables; 17% reported who, where and when their study population was recruited; and 4% categorised stroke type. Twelve (16%) of the 76 studies attained a good overall rating and 42 (55%) had a moderate overall rating. The remaining studies (29%) had a poor overall rating (see Table 4 on the eAddenda).

Meta-analyses

The meta-analyses are shown as streamlined forest plots in Figures 2 to 11. Detailed forest plots, are shown in Figures 12 to 21 on the eAddenda.

Effect of secondary task domain on mobility parameters in people after stroke

Meta-analyses were conducted for several gait parameters, including speed, cadence, stride length, stride time and Timed Up and Go test (Figures 2 to 6, and Tables 3 and 4 on the eAddenda). Meta-analyses were not performed for any cognitive measures due to the limited number of studies for a given task domain (< 3). Gait speed was the most commonly assessed dual-task walking measure (Figure 2, and Table 3 on the eAddenda).

Overall, there was a significant effect on gait speed when a secondary task was imposed during walking. A decrement in gait speed (m/s) was found when walking was performed simultaneously with mental tracking (MD −0.11, 95% CI −0.14 to −0.08), language (MD −0.10, 95% CI −0.15 to −0.04), manual tasks (MD −0.13, 95% CI −0.18 to −0.08) or discrimination and decision-making (MD −0.05, 95% CI −0.09 to −0.01). Manual tasks induced slightly greater DTI on gait speed compared to cognitive tasks. Among cognitive tasks, the effects of DTI on gait speed during mental tracking and language tasks were more pronounced than during other cognitive task domains (Figure 2).

Cadence decreased with the addition of a mental tracking task (MD −10, 95% CI −15 to −4), with similar results on the sensitivity analysis (Figure 3). Adding a language task had a similar effect (MD −9, 95% CI −15 to −3), although no sensitivity analysis was performed. A sensitivity analysis of adding a manual task showed reduced cadence among participants with chronic stroke, although not on the primary analysis (Figure 3).

Stride length (*m*) decreased with the addition of a mental tracking task (MD −0.07, 95% CI −0.13 to −0.01), language task (MD −0.09, 95% CI −0.16 to −0.01) or manual task (MD −0.11, 95% CI −0.18 to −0.04). The sensitivity analyses (mental tracking and manual tasks only) had similar results (Figure 4).

Adding a mental tracking task induced an increase in stride time (MD 0.05 seconds, 95% CI 0.01 to 0.09), with a similar result on the sensitivity analysis (Figure 5). Adding a manual task had a similar effect, although it was not evident on the sensitivity analysis. Adding a mental tracking task slowed performance on the Timed Up and Go test (MD −3 seconds, 95% CI 1 to 6), as shown in Figure 6.

Effect of different tasks within the same cognitive or manual task domain on gait speed in people after stroke

We also examined how DTI was affected by different tasks within the same domain. Based on the available data, analyses were conducted for mental tracking (Figure 7), discrimination and decision-making (Figure 8), language (Figure 9) and manual task domains (Figure 10). Gait speed was the primary outcome measure across all

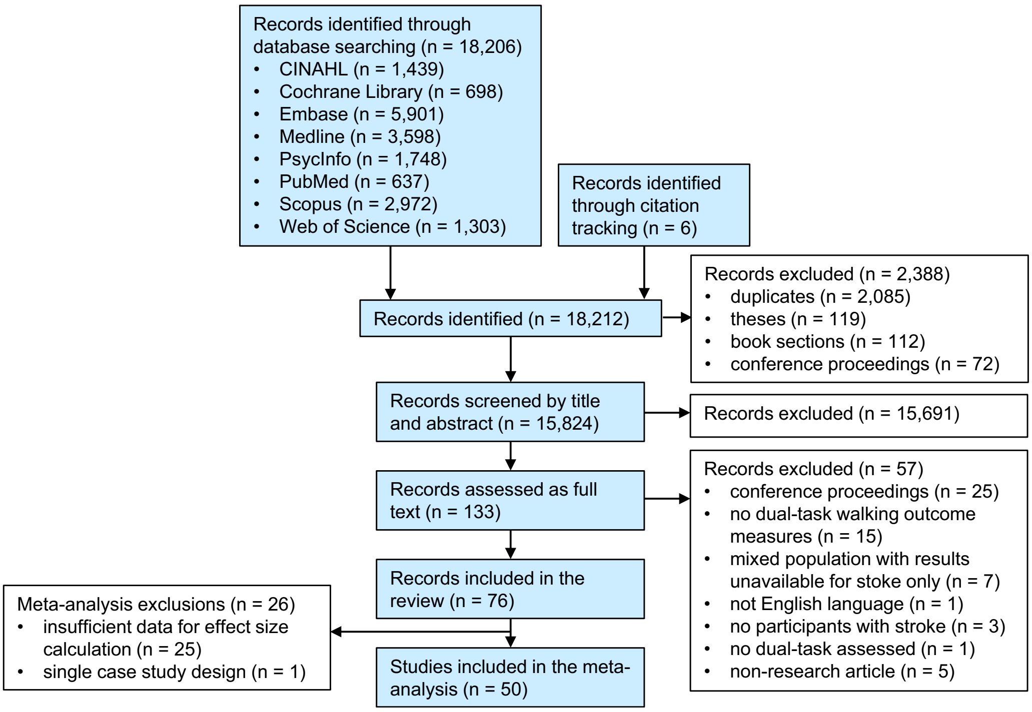

Figure 1. Flow of studies through the review.

domains. Within the mental tracking task domain, serial 1 subtractions (−0.17 m/s, 95% CI −0.25 to −0.10) tended to induce a greater DTI on gait speed than serial 3 subtractions (−0.10 m/s, 95% CI −0.15 to −0.05), although there was substantial uncertainty inherent in these estimates. The effect of the auditory 1-back task was uncertain (−0.08 m/s, 95% CI −0.22 to 0.06) (Figure 7). For the discrimination and decision-making domain, classification tasks induced a small DTI on gait speed (−0.07 m/s, 95% CI −0.12 to −0.02), while the auditory Stroop tests had no effect (−0.02 m/s, 95% CI −0.05 to 0.01) (Figure 8). For the language domain, spontaneous speech (−0.11 m/s, 95% CI −0.19 to −0.02) and category naming tasks (−0.09 m/s, 95% CI −0.16 to −0.02) induced similar DTI (Figure 9). For the manual task domain, the degree of DTI on gait speed was also similar for cup holding (−0.14 m/s, 95% CI −0.21 to −0.08) and tray holding tasks (−0.14 m/s, 95% CI −0.18 to −0.09) (Figure 10).

Dual-task interference pattern in people after stroke

Twenty-four datasets from 15 studies[10,12,20,21,23,41,60,63,67–73] reported whether there were significant differences between the walking and secondary task performance during single-task and dual-task conditions (see Table 3 on the eAddenda). Corresponding DTI patterns for dual-task conditions were identified.

Among these datasets, more than half were classified as showing a mutual interference pattern (ie, deterioration of both the mobility and the secondary task performances under a dual-task condition).[10,12,21,23,60,67,69,71,72] The secondary tasks included mental tracking (n = 5),[10,21,60,67,69] language (n = 2),[23,71] visuospatial (n = 2),[10,21] short-term memory (n = 1),[12] and discrimination and decision-making tasks (n = 2).[10,72] Six of the 24 datasets[23,60,63,72] were classified as showing a 'mobility interference' pattern. There was a degradation in mobility performance, but no changes in visuospatial,[23] mental tracking (n = 4),[23,60,63] and discrimination and decision-making[72] task performance. Five of the 24 datasets from the two studies[41,73] showed a 'cognitive interference' pattern. There was a deterioration in three language tasks and two mental tracking tasks, but no significant changes in walking performance. One dataset showed 'no interference' pattern.[21] Neither walking nor cognitive performances demonstrated any changes during the auditory clock test (see Table 3 on the eAddenda).

Comparison of DTI between people with and without stroke

Additional meta-analyses were conducted to compare the DTI between individuals with stroke and age-matched controls. Studies included in the analyses assessed walking speed during manual or mental tracking tasks (Figure 11). Adding a manual task increased DTI in gait speed (MD −0.07 m/s), although the estimate was imprecise (95% CI −0.18 to 0.03) in people after stroke (at all stages) when compared with their aged-matched peers without stroke (MD −0.07, 95% CI −0.10 to −0.03). This trend was slightly less evident in sensitivity analysis for individuals with chronic stroke (Figure 11), suggesting that both analyses may have been underpowered. The effect of adding a mental tracking task on DTI clearly did not differ between participants with and without stroke (Figure 11).

Publication bias of meta-analyses

Publication bias was present in the primary meta-analyses: for gait speed during mental tracking, language and manual tasks; for cadence during mental tracking tasks; for stride length during manual tasks; for stride time during mental tracking and manual tasks; and for Timed Up and Go during mental tracking tasks. For the sensitivity analyses, publication bias was observed: for gait speed during manual tasks; for cadence during mental tracking tasks; for stride length during manual tasks; and for stride time during mental tracking (see Table 5 on the eAddenda).

Discussion

This systematic review and meta-analysis examined the effect of different secondary tasks on gait parameters in people after stroke. The results showed that the degree and pattern of DTI during dual-task walking varied with the component tasks among individuals with stroke. The degree of DTI on walking speed in people with chronic stroke was comparable to their able-bodied peers.

In the analyses of the effect of secondary task domain on mobility parameters in people after stroke, gait speed was the most used measure of dual-task walking (Figure 2, and Table 3 on the eAddenda). It also appeared to be the most sensitive parameter for detecting DTI in mobility, regardless of the secondary task domain

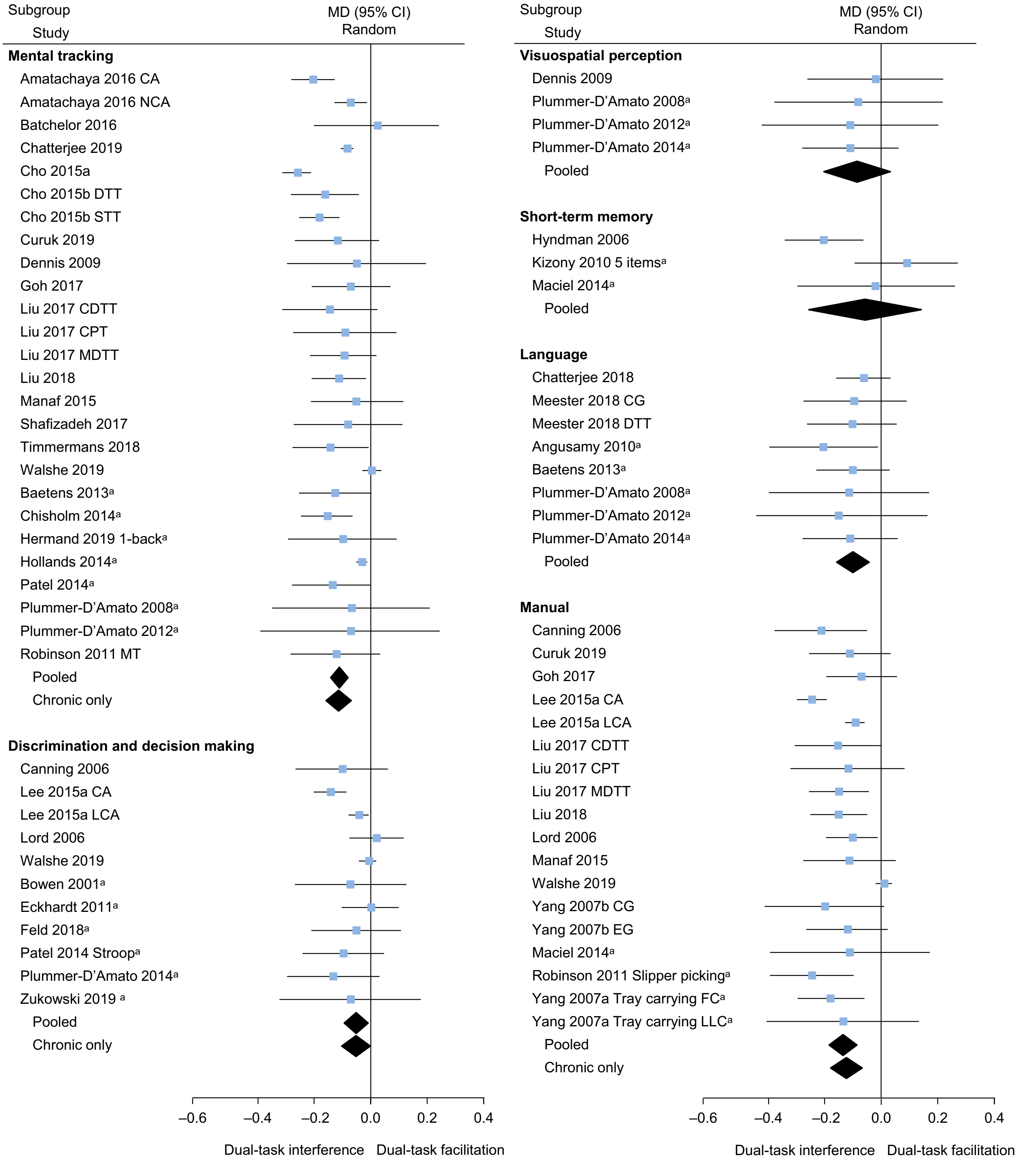

Figure 2. Forest plot of effect of secondary tasks on gait speed *(m/s)* in people with stroke. A total of 37 studies (914 participants) were involved in the primary analysis, and 18 studies (344 participants) in the sensitivity analysis among people with chronic stroke.
CA = community ambulating group, CDTT = cognitive dual-task training group, CG = control group, CPT = conventional physiotherapy group, DTT = dual-task training group, EG = exercise group, FC = full community ambulating group, LCA = Limited community ambulating group, LLC = least limited community ambulating group, MDTT = motor dual-task training group, MT = mental tracking, NCA = non-community ambulating group, SS1 = serial subtractions by 1, STT = single-task training group, TG = target group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

used. This is consistent with previous findings among older adults and other neurological populations.[28,30,46] With the exception of walking conditions involving discrimination and decision-making tasks, changes in gait speed (−0.10 to −0.13 m/s) met or exceeded the minimal clinically important difference value (0.1 m/s),[74] as shown in Figure 2.

The observed reductions in gait speed and Timed Up and Go time (Figure 6) during mental tracking and language task suggest that tasks requiring internally driven responses cause relatively larger DTI than those requiring externally driven responses (eg, visuospatial perception or discrimination and decision-making tasks).[28,30] Common neural networks may be involved during walking,[75]

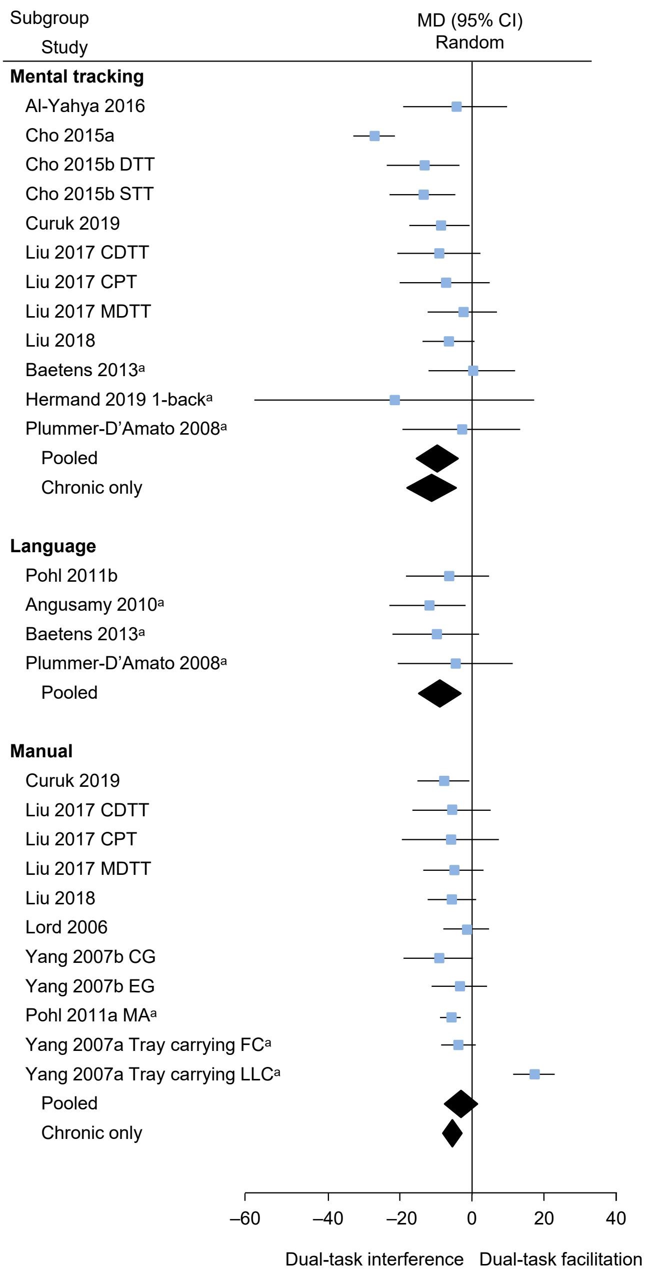

Figure 3. Forest plot of effect of secondary tasks on cadence *(steps/min)* in people with stroke. A total of 15 studies (355 participants) were involved in the primary analyses, and eight studies (220 participants) in the sensitivity analyses among people with chronic stroke.
CDTT = cognitive dual-task training group, CG = control group, CPT = conventional physiotherapy group, DTT = dual-task training group, EG = exercise group, FC = full community ambulating group, LLC = least limited community ambulating group, MA = more-affected hand movement, MDTT = motor dual-task training group, STT = singletask training group.
[a] Study included people within 6 months of stroke onset or a mix of people with subacute and chronic stroke.

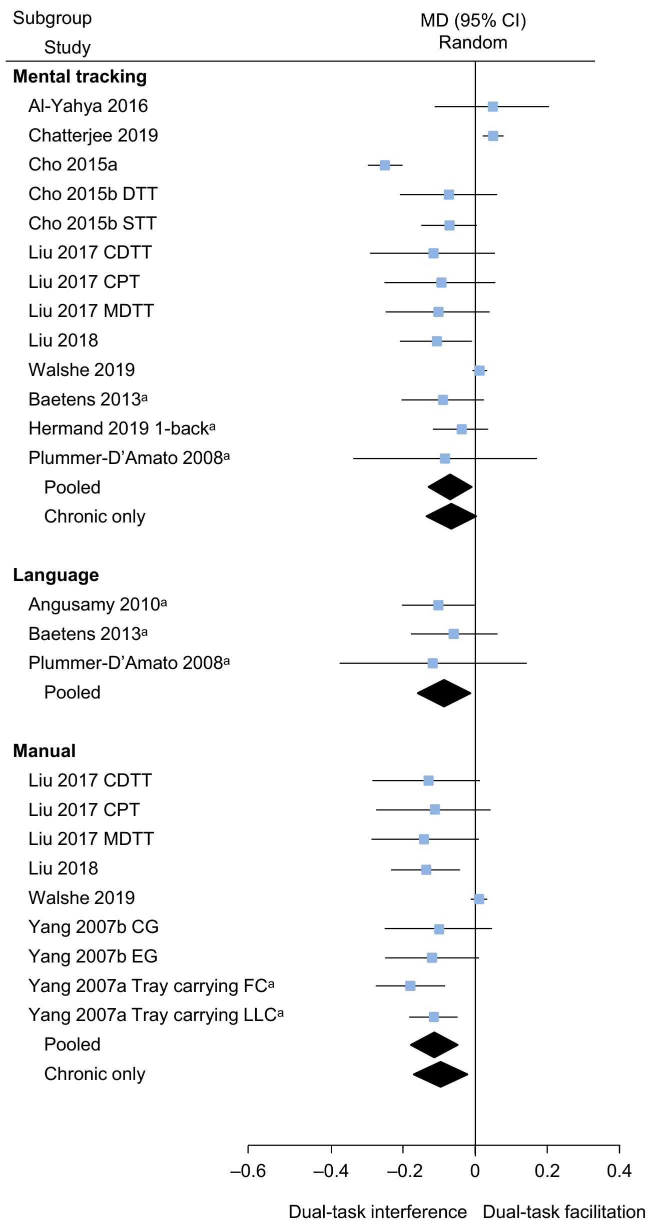

Figure 4. Forest plot of effect of secondary tasks on stride length *(m)* in people with stroke. A total of 13 studies (320 participants) were involved in the primary analyses, and eight studies (204 participants) for the sensitivity analyses involving people with chronic stroke.
CDTT = cognitive dual-task training group, CG = control group, CPT = conventional physiotherapy group, EG = exercise group, FC = full community ambulating group, LLC = least limited community ambulating group, MDTT = motor dual-task training group.
[a] Study included people within 6 months of stroke onset or a mix of people with subacute and chronic stroke.

dual-tasking,[76] and when giving internally driven and externally driven responses.[77] The bottleneck model suggests that greater overlap of these networks may result in more competition for cognitive resources, and thus more severe DTI. Further investigation into the underlying neural mechanism of DTI is warranted.

The DTI effect on gait induced by manual and mental tracking tasks also varied according to the specific gait parameter that was assessed (Figures 2 to 5). These findings are consistent with those of Lu et al,[78] who compared the effect of a mental tracking task (serial 7 subtractions) and a manual task (holding a bottle of water on a tray) on walking in healthy younger adults. Both tasks resulted in speed and stride length reductions compared to walking alone. However, decreased cadence and increased stride time were only found during walking involving the mental tracking task. Different brain activation patterns were also identified during dual-task walking with manual versus mental tracking tasks. Using functional near-infrared spectroscopy, Lu et al revealed an increased motor cortex activation during walking with manual and cognitive tasks. A strong and sustained activation of the left prefrontal cortex was also observed during walking with serial 7 subtractions. This is in contrast with only weak activation of this brain region during the initial phases of single-task walking and walking while balancing a bottle of water on a tray.[78]

Also in line with the findings of Lu et al,[78] reductions in stride length were more pronounced (ie, a stronger DTI effect) during manual tasks than mental tracking tasks (Figure 4). This may be related to reductions in arm-swing amplitude when engaging in

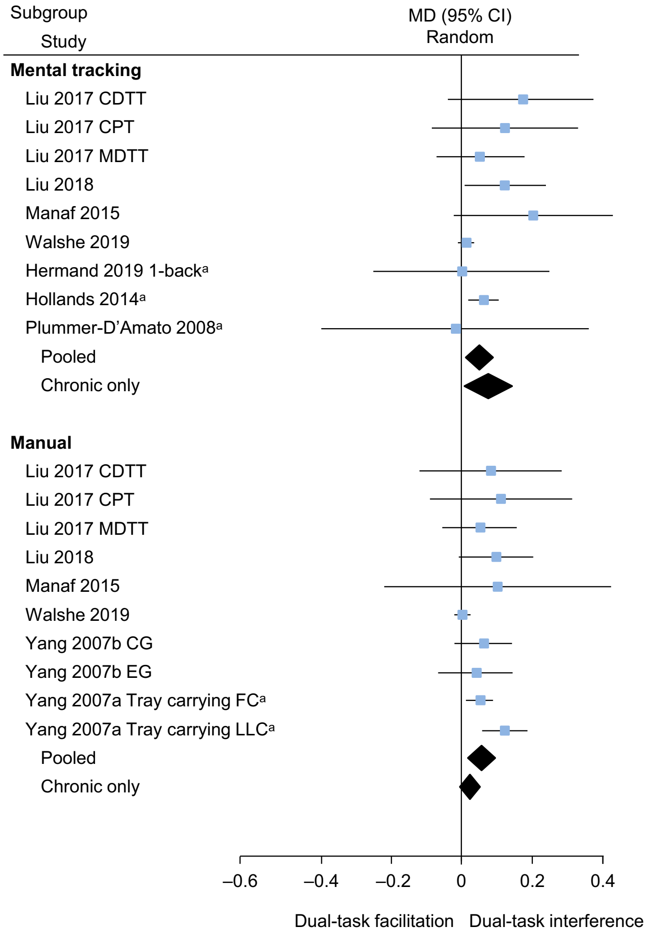

Figure 5. Detailed forest plot of effect of secondary tasks on stride time *(s)* in people with stroke. A total of nine studies (168 participants) were involved in the primary analyses, and five studies (97 participants) for the sensitivity analyses among people with chronic stroke.
CG = control group, DTT = dual-task training group, EG = experimental group, STT = single-task training group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

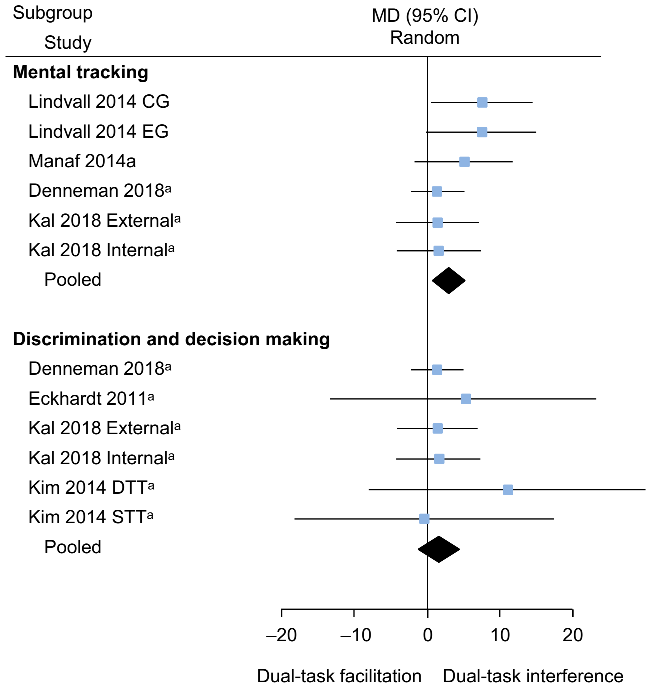

Figure 6. Detailed forest plot of effect of secondary tasks on Timed Up and Go *(s)* in people with stroke. A total of six studies (256 participants) were involved in the primary analyses. No further sensitivity analyses were conducted.
CG = control group, DTT = dual-task training group, EG = experimental group, External = external focus instruction group, Internal = internal focus instruction group, STT = single-task training group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

manual tasks. Previous research has shown that when one or both arm-swings were restrained, a decrease in stride length was observed in comparison to normal walking without restraints.[79] During manual tasks (eg, cup holding), reduced stride length could be the result of restricted arm movements. A controlled study comparing dual-task walking with manual tasks and standalone walking with arm-swings restrained at similar arm positions may help delineate the effect of dual-tasking from that of arm-swing restriction during manual tasks.

In the analyses of the effect of different tasks within the same secondary task domain in people after stroke, it was interesting to consider whether the degree of DTI during walking is more severe with increasing complexity of the secondary tasks involved. Task complexity can be indicated by the level of performance under single-task conditions.[1] However, this was rarely reported in the included studies, and examination of the effect of task complexity on DTI for task categories was limited. Inferences concerning task complexity were instead based on previous literature.

For the discrimination and decision-making domain, neutral stimuli used in classification tasks are considered to be less difficult than tasks involving congruent or incongruent stimuli such as those associated with auditory Stroop tasks.[80] For the mental tracking domain, two previous studies compared the complexity of serial 3 and serial 7 subtraction.[45,81] Both studies reported a significantly greater number of correct responses for serial 3 than for serial 7 subtractions under single-task conditions, thus indicating the latter to be relatively more complex than the former. Therefore, it is reasonable to assume that serial 3 would be more complex than serial 1 subtractions.

Overall, our results are counterintuitive, in that serial 1 subtractions induced a greater DTI than serial 3 subtractions. Classification tasks also induced greater DTI than auditory Stroop tasks. These findings suggest that DTI, especially during cognitive-mobility dual-task conditions, is a complex phenomenon affected by multiple factors. In addition to the aforementioned competition for neural circuitry,[1,82] our findings are also supported by the capacity sharing model of attention theories. This model suggests that interference occurs when cognitive demand exceeds a finite attention capacity.[1] As indicated by Kahnamen,[1] allocation of finite attention is malleable and highly responsive to individual arousal level, ever-changing momentary intentions, and affected by component task demands that exceed the available capacity.[1] During dual-task walking, people might prioritise either component task according to their ability, as well as their own self-perceived challenges associated with the task. For instance, participants may have considered serial 3 subtractions to be too challenging, and thus prioritised walking over the cognitive task, overtly or covertly, resulting in a lower decrement to mobility performance. Yang et al[45] also showed that counting accuracy was reduced when a serial 3 subtraction task was imposed during an obstacle-crossing task, but not when the more complex (serial 7 subtraction) task was used. On the other hand, spontaneous speech questions incorporate personal experiences, opinions, and content relevant to daily life (see Table 3 on the eAddenda). These questions may be more meaningful and engaging than category naming tasks. As a result, participants may covertly be more aroused or may overtly prioritise cognitive tasks over walking in such a scenario, thereby reducing walking speed.

For manual tasks, walking while holding a tray demonstrated an effect comparable to cup holding (Figure 10). The relative similarity and task-dependent movement may explain this result. For both tasks, arm-swing was restricted, rendering a shorter stride length and reduced walking speed.[79] Participants may have also intentionally

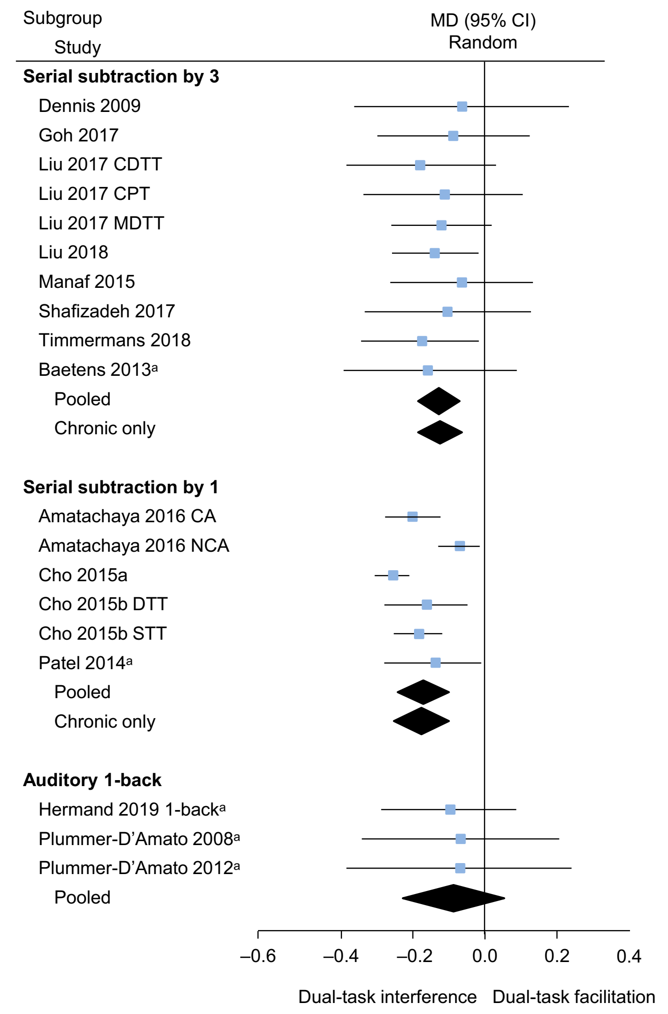

Figure 7. Detailed forest plot of effect of different mental tracking tasks on gait speed *(m/s)* in people with stroke. A total of 15 studies (362 participants) were involved in the primary analyses and 10 studies (301 participants) for the sensitivity analysis among people with chronic stroke.
CA = community ambulatory group, CDTT = cognitive dual-task training group, CPT = conventional physiotherapy training group, DTT = dual-task training group, MDTT = motor dual-task training group, NCA = non-community ambulatory group, STT = single-task training group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

adjusted their gait (ie, shorter stride length) to avoid dropping objects from the tray or spilling water from the cup.[78]

In the analyses of dual-task interference patterns in people after stroke, most datasets showed mobility-related interference. These findings suggest that people after stroke tend to reduce walking speed when instructed to perform both tasks equally well or when not explicitly instructed to prioritise either task (see Table 3 on the eAddenda). Similar findings were reported by Yogev-Seligmann et al,[83] when dual-task walking performance was compared during conditions with and without prior task prioritisation instructions among healthy younger and older adults. Both younger and older adults showed reductions in walking speed when no explicit prioritisation was given.

Our analyses of DTI patterns indicate that mutual interference was the most common and was often induced by a secondary task requiring internally driven responses. These findings are consistent with those of previous systematic reviews[28,46] and suggest that cognitive tasks that require internally driven responses may impose greater cognitive loading, thereby resulting in greater DTI.

Intriguingly, there were no clear differences in DTI for gait speed during manual or mental tracking tasks between people with and without a history of stroke (Figure 11). This may be explained by the

Figure 8. Forest plot of effect of different discrimination and decision-making tasks on gait speed *(m/s)* in people with stroke. A total of nine studies (154 participants) were involved in the primary analyses. No further sensitivity analyses were conducted.
CA = community ambulating group, LCA = limited community ambulating group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

modest difference in cognitive function and mobility between the two groups. A large proportion of studies involved participants with chronic stroke who had relatively good cognitive and ambulatory function. The results of the sensitivity analyses also showed no clear differences between able-bodied older adults and people with chronic stroke (Figure 11). People with chronic stroke may have regained gait automaticity, as indicated by increased speed and

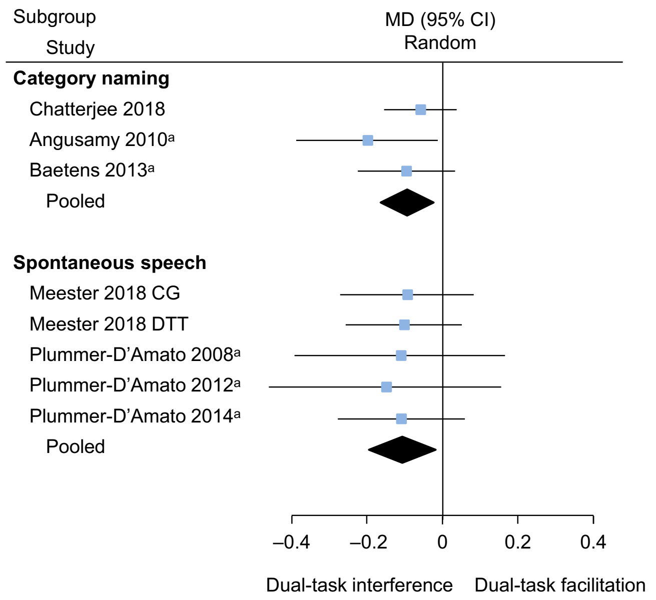

Figure 9. Forest plot of effect of different language tasks on gait speed *(m/s)* in people with stroke. A total of seven studies (176 participants) were involved in the primary analyses. No further sensitivity analyses were conducted for people with chronic stroke.
CG = control group, DTT = dual-task training group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

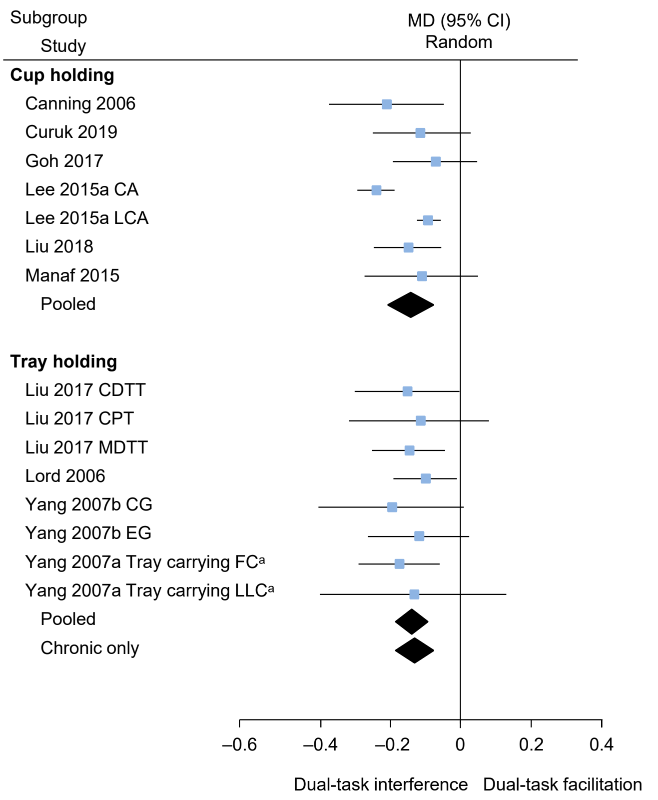

Figure 10. Forest plot of effect of different manual tasks on dual-task gait speed *(m/s)* in people with stroke. A total of 10 studies (235 participants) were involved in the primary analyses, and nine studies (205 participants) in the sensitivity analysis among people with chronic stroke.
CA = community ambulatory group, CDTT = cognitive dual-task training group, CG = control group, CPT = conventional physiotherapy training group, EG = exercise group, FC = full community group, LLC = least limited community group, LCA = limited community ambulatory group, MDTT = motor dual-task training group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

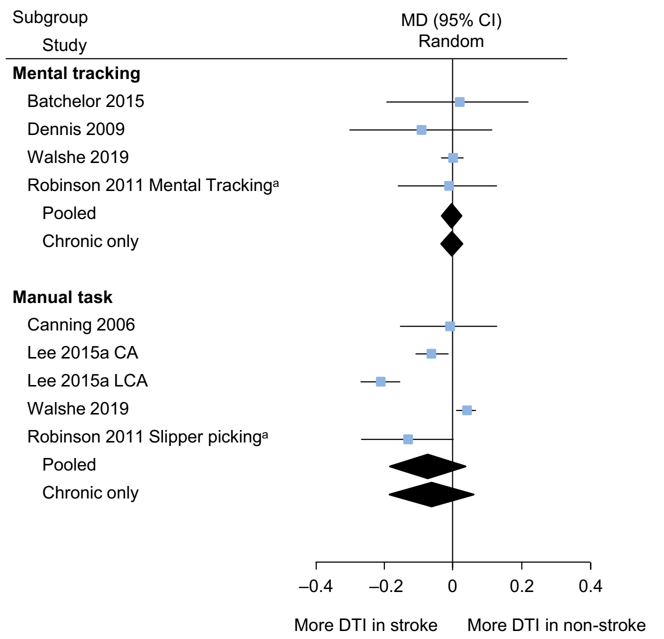

Figure 11. Forest plot of comparison of dual-task interference on gait speed *(m/s)* between people with and without stroke. A total of six studies (127 people with stroke, 109 participants without stroke) were involved in the primary analyses. Five studies (97 people with stroke, 79 participants without stroke) were included in the sensitivity analyses.
CA = community ambulating group, DTI = dual-task interference (ie, dual-task performance – single-task performance), LCA = limited community ambulating group.
[a] Study included people within 6 months of stroke onset or a mix of people with sub-acute and chronic stroke.

reduced gait variability.[84,85] DTI is also considered to be a surrogate measure of gait automaticity.[3] Overall, the lack of between-group difference reported here was not consistent with the findings of a recent systematic review by DeBlock-Bellamy et al,[46] which found a larger DTI among people after stroke compared to age-matched healthy participants. However, their conclusion was based on a narrative synthesis of results derived from seven studies involving very different testing protocols and outcome measures. The results of the current meta-analyses were based on groups of three or more studies reporting the same mobility outcome (ie, walking speed on level-ground). Additionally, each analysis was based on a group of studies involving the same secondary task category (manual tasks, mental tracking tasks). In contrast, studies using different secondary task categories in the testing protocol were mixed in that systematic review to generate the overall conclusion. These factors may explain the discrepancy between our current review and theirs.

Among the 76 included studies, few reported who, where and when their study participants were recruited; this limits study replicability. Descriptions of stroke-related characteristics (eg, severity or location of stroke) were also missing in most studies. Less than half of the included studies made statistical adjustments to account for potential confounding variables, justified sample sizes and power calculations, or reported variance and effect estimates. Only 16% of the studies included sample sizes $\geq$ 50, which may have limited the statistical power of these studies.[86]

As noted earlier, self-perceived challenge may have covertly influenced task prioritisation, which in turn affected component task performance. However, only one study[87] addressed this issue by measuring perceived challenge with physiological measures (skin conductance) during single-task and dual-task performance. Task prioritisation instructions were not reported in 72% of studies (see Table 3 on the eAddenda). There was also a lack of cohort studies investigating the effect of stroke chronicity and other characteristics of DTI during walking.

The studies included in this review involved different designs, testing protocols and outcome measures, and the participants with stroke had clinical characteristics that varied in terms of stroke type, stage and severity. These factors may explain the heterogeneity across studies in the primary analyses. Most studies did not report the impact of walking on secondary tasks, nor the resultant DTI pattern for individual participants. The lack of information on cognitive task performance during single-tasks also limited our ability to examine the effect of task complexity on DTI. Most studies did not include an able-bodied control group; this limited the comparability of DTI effects between people with and without a history of stroke.

Publication bias was present in several analyses involving language, manual or mental tracking tasks. This may be explained by the relatively small number of studies (mostly < 10) that could be identified and pooled in the meta-analyses. However, a large number of additional studies (9 to 949) with zero effect would be needed to nullify the observed effects of DTI during walking conditions involving these tasks. These findings suggest that publication bias may have resulted in an underestimation in the magnitude of DTI during dual-task walking, rather than an overestimation. Therefore, certainty of the observed evidence should be considered robust.[56]

In conclusion, this review showed that the degree and pattern of DTI depends on the choice of component task domain and subcategory. A cognitive task of relatively lower complexity also caused a greater degree of DTI during walking than a more complex task of the same domain. Counterintuitively, people after stroke did not show a greater DTI for walking speed than their able-bodied peers during manual or mental tracking tasks. Clinicians may need to select dual-task combinations with standardised procedures in order to capture specific deficits in dual-task performance, index functional abilities under more challenging situations than routine clinical tests, and individually tailor corresponding interventions for people after stroke. An inventory of daily habits, ecological interactions, and aptitude in different cognitive domains (as determined by corresponding cognitive assessments) may help in the initial identification of specific dual-task combinations that are most appropriate. There is also a need to study possible associations between DTI and stroke chronicity, cognitive/physical impairment and specific neuropsychological deficits (eg, decline in memory or mental tracking ability). This may produce a more comprehensive picture of dual-task mobility function and assist in delineating specific dual-task walking mechanisms among people after stroke. This review also reveals the great diversity in testing protocols across included studies. Dual-task mobility assessment standardisation is needed for evaluating the effect of treatment on dual-task function, and for comparing function within and between groups at differing stages of stroke recovery.

What was already known on this topic: Performing a second task while walking can impair performance of one or both tasks. In people with stroke, this dual-task interference can impact independence, participation and safety. Dual-task interference in walking may differ with the nature of the concurrent task and the time since stroke, but the extensive evidence about this has not been adequately summarised.
What this study adds: In people with stroke, manual and mental tracking tasks imposed the greatest dual-task interference on gait speed. Although the nature of the concurrent task affected the extent of dual-task interference, the time since stroke did not. When evaluating mobility and planning rehabilitation, clinicians should select dual-task assessments that correspond to the daily habits and physical demands of people after stroke.

Footnotes: [a] Endnote X9, Thomas Reuters, New York, USA.
[b] GetData Graph digitizer 2.26, ShareIt!, Bochum, Germany.
[c] Review Manager V.5.3, The Nordic Cochrane Centre, Copenhagen, Denmark.
[d] Comprehensive Meta-Analysis V.3, Biostat, Englewood, NJ, USA.

eAddenda: Figures 12 to 21, Tables 2 to 5 and Appendix 1 can be found online at https://doi.org/10.1016/j.jphys.2021.12.009.

Ethics approval: Not applicable.

Competing interests: None.

Sources of support: This study was supported by a research grant provided by the Research Grants Council (151594/16M). CSLT and TM were supported by The Hong Kong Polytechnic University PhD studentships (RUNV, RL27). The funding sources have no role in the collection, analysis, and interpretation of data, in the writing of the report, or in the decision to submit the article for publication.

Acknowledgements: We genuinely thank Dr Raymond Chung for his advice and guidance regarding the data analyses, Dr Deborah Jehu who assisted with the data collection at the beginning of the project and Ms Virginia Lau for her assistance in conducting the forward search.

Provenance: Not invited. Peer reviewed.

Correspondence: Marco Yiu-Chung Pang, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong. Email: marco.pang@polyu.edu.hk

References

1. Kahneman D. Attention and effort. Vol. 1063. CiteSeer; 1973.
2. Pashler H. Dual-task interference in simple tasks: data and theory. *Psychol Bull*. 1994;116:220.
3. Paul SS, Ada L, Canning CG. Automaticity of walking – implications for physiotherapy practice. *Phys Ther Rev*. 2005;10:15–23.
4. Wickens CD. Multiple resources and performance prediction. *Theor Issues Ergon Sci*. 2002;3:159–177.
5. Merrian-Webster. Cross talk. In: *Merrian-Webster Dictionary*. 2009.
6. Plummer P, Eskes G, Wallace S, Giuffrida C, Fraas M, Campbell G, et al. Cognitive-motor interference during functional mobility after stroke: state of the science and implications for future research. *Arch Phys Med Rehabil*. 2013;94:2565–2574.e6.
7. Amatachaya S, Chuadthong J, Thaweewannaku T, Srisim K, Phonthee S. Levels of community ambulation ability in patients with stroke who live in a rural area. *Malays J Med Sci*. 2016;23:56–62.
8. Lee KB, Lim SH, Ko EH, Kim YS, Lee KS, Hwang BY. Factors related to community ambulation in patients with chronic stroke. *Top Stroke Rehabil*. 2015;22:63–71.
9. Haggard P, Cockburn J, Cock J, Fordham C, Wade D. Interference between gait and cognitive tasks in a rehabilitating neurological population. *J Neurol Neurosurg Psychiatr*. 2000;69:479–486.
10. Patel P, Bhatt T. Task matters: influence of different cognitive tasks on cognitive-motor interference during dual-task walking in chronic stroke survivors. *Top Stroke Rehabil*. 2014;21:347–357.
11. Harley C, Boyd J, Cockburn J, Collin C, Haggard P, Wann JP, et al. Disruption of sitting balance after stroke: influence of spoken output. *J Neurol Neurosurg Psychiatr*. 2006;77:674–676.
12. Hyndman D, Ashburn A, Yardley L, Stack E. Interference between balance, gait and cognitive task performance among people with stroke living in the community. *Disabil Rehabil*. 2006;28:849–856.
13. Andersson AG, Kamwendo K, Seiger A, Appelros P. How to identify potential fallers in a stroke unit: validity indexes of four test methods. *J Rehabil Med*. 2006;38:186–191.
14. Baetens T, De Kegel A, Palmans T, Oostra K, Vanderstraeten G, Cambier D. Gait analysis with cognitive-motor dual tasks to distinguish fallers from nonfallers among rehabilitating stroke patients. *Arch Phys Med Rehabil*. 2013;94:680–686.
15. Tsang CSL, Pang MYC. Association of subsequent falls with evidence of dual-task interference while walking in community-dwelling individuals after stroke. *Clin Rehabil*. 2020;34:971–980.
16. Lord SE, Weatherall M, Rochester L. Community ambulation in older adults: which internal characteristics are important? *Arch Phys Med Rehabil*. 2010;91:378–383.
17. Sturm JW, Donnan GA, Dewey HM, Macdonell RA, Gilligan AK, Srikanth V, et al. Quality of life after stroke. *Stroke*. 2004;35:2340–2345.
18. Pound P, Gompertz P, Ebrahim S. A patient-centred study of the consequences of stroke. *Clin Rehabil*. 1998;12:338–347.
19. Bowen A, Wenman R, Mickelborough J, Foster J, Hill E, Tallis R. Dual-task effects of talking while walking on velocity and balance following stroke. *Age Ageing*. 2001;30:319–323. http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/101/CN-00371101/frame.html
20. Cockburn J, Haggard P, Cock J, Fordham C. Changing patterns of cognitive-motor interference (CMI) over time during recovery from stroke. *Clin Rehabil*. 2003;17:167–173.
21. Dennis A, Dawes H, Elsworth C, Collett J, Howells K, Wade DT, et al. Fast walking under cognitive-motor interference conditions in chronic stroke. *Brain Res*. 2009;1287:104–110. http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/632/CN-00742632/frame.html
22. Hyndman D, Ashburn A. "Stops walking when talking" as a predictor of falls in people with stroke living in the community. *J Neurol Neurosurg Psychiatr*. 2004;75:994–997.
23. Plummer-D'Amato P, Altmann LJP, Saracino D, Fox E, Behrman AL, Marsiske M. Interactions between cognitive tasks and gait after stroke: A dual task study. *Gait Posture*. 2008;27:683–688.
24. Regnaux JP, David D, Daniel O, Smail DB, Combeaud M, Bussel B. Evidence for cognitive processes involved in the control of steady state of walking in healthy subjects and after cerebral damage. *Neurorehabil Neural Repair*. 2005;19:125–132.
25. Smulders K, van Swigchem R, de Swart BJM, Geurts ACH, Weerdesteyn V. Community-dwelling people with chronic stroke need disproportionate attention while walking and negotiating obstacles. *Gait Posture*. 2012;36:127–132.
26. Takatori K, Okada Y, Shomoto K, Ikuno K, Nagino K, Tokuhisa K. Effect of a cognitive task during obstacle crossing in hemiparetic stroke patients. *Physiother Theory Pract*. 2012;28:292–298.
27. Yang YR, Chen YC, Lee CS, Cheng SJ, Wang RY. Dual-task-related gait changes in individuals with stroke. *Gait Posture*. 2007;25:185–190.
28. Al-Yahya E, Dawes H, Smith L, Dennis A, Howells K, Cockburn J. Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev*. 2011;35:715–728.
29. Smith E, Cusack T, Blake C. The effect of a dual task on gait speed in community dwelling older adults: a systematic review and meta-analysis. *Gait Posture*. 2016;44:250–258.
30. Smith E, Cusack T, Cunningham C, Blake C. The influence of a cognitive dual task on the gait parameters of healthy older adults: a systematic review and meta-analysis. *J Aging Phys Act*. 2017;25:671–686.
31. Ghai S, Ghai I, Effenberg AO. Effects of dual tasks and dual-task training on postural stability: a systematic review and meta-analysis. *Clin Intervent Aging*. 2017;12:557–577.
32. Fritz NE, Cheek FM, Nichols-Larsen DS. Motor-cognitive dual-task training in persons with neurologic disorders: a systematic review. *J Neurolog Phys Ther*. 2015;39:142–153.
33. Lees A, Smith EJB. Cognitive deficits in the early stages of Parkinson's disease. *Brain*. 1983;106:257–270.
34. de Haan EH, Nys GM, Van Zandvoort MJ. Cognitive function following stroke and vascular cognitive impairment. *Curr Opin Neurol*. 2006;19:559–564.
35. Chiaravalloti ND, DeLuca J. Cognitive impairment in multiple sclerosis. *Lancet Neurol*. 2008;7:1139–1151.
36. Lapointe R, Lajoie Y, Serresse O, Barbeau H. Functional community ambulation requirements in incomplete spinal cord injured subjects. *Spinal Cord*. 2001;39:327.
37. Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. *J Mov Disord*. 2008;23:329–342.
38. Chee R, Murphy A, Danoudis M, Georgiou-Karistianis N, Iansek RJB. Gait freezing in Parkinson's disease and the stride length sequence effect interaction. *Brain*. 2009;132:2151–2160.
39. Goldie PA, Matyas TA, Evans OM. Gait after stroke: initial deficit and changes in temporal patterns for each gait phase. *Arch Phys Med Rehail*. 2001;82:1057–1065.

40. Patterson SL, Forrester LW, Rodgers MM, Ryan AS, Ivey FM, Sorkin JD, et al. Determinants of walking function after stroke: differences by deficit severity. *Arch Phys Med Rehabil*. 2007;88:115–119.
41. Tisserand R, Armand S, Allali G, Schnider A, Baillieul S. Cognitive-motor dual-task interference modulates mediolateral dynamic stability during gait in post-stroke individuals. *Hum Mov Sci*. 2018;58:175–184.
42. O'Shea S, Morris ME, Iansek R. Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks. *Phys Ther*. 2002;82:888–897.
43. Amatachaya S, Srisim K, Thaweewannakij T, Arrayawichanon P, Amatachaya P, Mato L. Failures in dual-task obstacle crossing could predict risk of future fall in independent ambulatory individuals with spinal cord injury. *Clin Rehabil*. 2019;33:120–127.
44. Allali G, Laidet M, Assal F, Armand S, Lalive PH. Walking while talking in patients with multiple sclerosis: the impact of specific cognitive loads. *Neurophysiol Clin*. 2014;44:87–93.
45. Yang L, Lam FM, Huang M, He C, Pang MY. Dual-task mobility among individuals with chronic stroke: changes in cognitive-motor interference patterns and relationship to difficulty level of mobility and cognitive tasks. *Eur J Phys Rehabil Med*. 2018;54:526–535.
46. Deblock-Bellamy A, Lamontagne A, Blanchette AK. Cognitive-locomotor dual-task interference in stroke survivors and the influence of the tasks: a systematic review. *Front Neurol*. 2020;11.
47. Moher D, Liberati A, Tetzlaff J, Altman D. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339:b2535.
48. Wardle J, Steel A. Systematic reviews in integrative medicine: a clinician's guide to publication. *Adv Integr Med*. 2015;2:103–109.
49. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropract Med*. 2016;15:155–163.
50. Deeks JJ, Higgins JP, Altman DG, Group CSM. Analysing data and undertaking meta-analyses. *Cochrane Handbook for Systematic Reviews of Interventions. Cochrane*. 2019:241–284.
51. Bond Jr CF, Wiitala WL, Richard FD. Meta-analysis of raw mean differences. *Psychol Methods*. 2003;8:406.
52. Borenstein MHL, Higgins JPT, Rothstein HR. Effect sizes based on means. In: *Introduction to Meta-Analysis*. Hoboken, USA: John Wiley & Sons, Ltd.; 2009.
53. Deeks JJ, Altman DG, Bradburn MJ. Statistical methods for examining heterogeneity and combining results from several studies in meta-analysis. In: *Systematic Reviews in Health Care: Meta-Analysis in Context. Second Edition*. Hoboken, USA: Wiley, Ltd; 2008:285–312.
54. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327:557.
55. Egger M, Smith GD, Schneider M, Minder CJB. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315:629–634.
56. Murad MH, Chu H, Lin L, Wang Z. The effect of publication bias magnitude and direction on the certainty in evidence. *BMJ Evid Based Med*. 2018;23:84–86.
57. Borenstein M. Software for publication bias. In: Rothstein HR, Sutton AJ, Borenstein M, eds. *Publication Bias in Meta-Analysis: Prevention, Assessment and Adjustments*. Chichester: Wiley; 2005.
58. Ben Assayag E, Shenhar-Tsarfaty S, Korczyn AD, Kliper E, Hallevi H, Shopin L, et al. Gait measures as predictors of poststroke cognitive function: evidence from the TABASCO study. *Stroke*. 2015;46:1077–1083.
59. Chisholm AE, Makepeace S, Inness EL, Perry SD, McIlroy WE, Mansfield A. Spatial-temporal gait variability poststroke: variations in measurement and implications for measuring change. *Arch Phys Med Rehabil*. 2014;95:1335–1341.
60. Chaikeeree N, Chinsongkram B, Saengsirisuwan V, Boonsinsukh R. Effect of cognitive task on components of 7 meter timed up-and-go test in persons with stroke. *Sci Asia*. 2018;44:247–256.
61. Denneman RPM, Kal EC, Houdijk H, Kamp JVD. Over-focused? The relation between patients' inclination for conscious control and single- and dual-task motor performance after stroke. *Gait Posture*. 2018;62:206–213.
62. Kal E, Houdijk H, van der Kamp J, Verhoef M, Prosée R, Groet E, et al. Are the effects of internal focus instructions different from external focus instructions given during balance training in stroke patients? A double-blind randomized controlled trial. *Clin Rehabil*. 2019;33:207–221.
63. Hermand E, Tapie B, Dupuy O, Fraser S, Compagnat M, Salle JY, et al. Prefrontal cortex activation during dual task with increasing cognitive load in subacute stroke patients: a pilot study. *Front Aging Neurosci*. 2019;11.
64. Pohl PS, Kemper S, Siengsukon CE, Boyd L, Vidoni ED, Herman RE. Dual-task demands of hand movements for adults with stroke: A pilot study. *Topics Stroke Rehabil*. 2011;18:238–247.
65. Kizony R, Levin MF, Hughey L, Perez C, Fung J. Cognitive load and dual-task performance during locomotion poststroke: a feasibility study using a functional virtual environment. *Phys Ther*. 2010;90:252–260.
66. Robinson CA, Shumway-Cook A, Matsuda PN, Ciol MA. Understanding physical factors associated with participation in community ambulation following stroke. *Disabil Rehabil*. 2011;33:1033–1042.
67. Al-Yahya E, Johansen-Berg H, Kischka U, Zarei M, Cockburn J, Dawes H. Prefrontal cortex activation while walking under dual-task conditions in stroke: a multimodal imaging study. *Neurorehabil Neural Repair*. 2016;30:591–599.
68. Hackney ME, Hall CD, Echt KV, Wolf SL. Application of adapted tango as therapeutic intervention for patients with chronic stroke. *J Geriatr Phys Ther*. 2012;35:206–217.
69. Manaf H, Justine M, Goh H-T. Effects of attentional loadings on gait performance before turning in stroke survivors. *PM & R*. 2015;7:1159–1166.
70. Yang L, He C, Pang MY. Reliability and validity of dual-task mobility assessments in people with chronic stroke. *PLoS One*. 2016;11:e0147833.
71. Pohl PS, Kemper S, Siengsukon CF, Boyd L, Vidoni E, Herman RE. Older adults with and without stroke reduce cadence to meet the demands of talking. *J Geriatr Phys Ther*. 2011;34:35–40.
72. Feld JA, Zukowski LA, Howard AG, Giuliani CA, Altmann LJ, Najafi B, et al. Relationship between dual-task gait speed and walking activity poststroke. *Stroke*. 2018;49:1296–1298.
73. Kemper S, McDowd J, Pohl P, Herman R, Jackson S. Revealing language deficits following stroke: the cost of doing two things at once. *Aging Neuropsychol Cogn*. 2006;13:115–139.
74. Bohannon RW, Glenney SS. Minimal clinically important difference for change in comfortable gait speed of adults with pathology: a systematic review. *J Eval Clin Pract*. 2014;20:295–300.
75. Takakusaki K, Tomita N, Yano M. Substrates for normal gait and pathophysiology of gait disturbances with respect to the basal ganglia dysfunction. *J Neurol*. 2008;255:19–29.
76. Leone C, Feys P, Moumdjian L, D'Amico E, Zappia M, Patti F. Cognitive-motor dual-task interference: a systematic review of neural correlates. *Neurosci Biobehav Rev*. 2017;75:348–360.
77. Benedek M, Jauk E, Beaty RE, Fink A, Koschutnig K, Neubauer AC. Brain mechanisms associated with internally directed attention and self-generated thought. *Sci Reports*. 2016;6:22959.
78. Lu C-F, Liu Y-C, Yang Y-R, Wu Y-T, Wang R-Y. Maintaining gait performance by cortical activation during dual-task interference: a functional near-infrared spectroscopy study. *PLoS One*. 2015;10:e0129390.
79. Eke-Okoro ST, Gregoric M, Larsson L-E. Alterations in gait resulting from deliberate changes of arm-swing amplitude and phase. *Clin Biomech*. 1997;12:516–521.
80. Hershman R, Levin Y, Tzelgov J, Henik A. Neutral stimuli and pupillometric task conflict. *Psychol Res*. 2021;85:1084–1092.
81. Bristow T, Jih CS, Slabich A, Gunn J. Standardization and adult norms for the sequential subtracting tasks of serial 3's and 7's. *Appl Neuropsychol Adult*. 2016;23:372–378.
82. Holtzer R, Verghese J, Xue X, Lipton RB. Cognitive processes related to gait velocity: results from the Einstein Aging Study. *Neuropsychol*. 2006;20:215.
83. Yogev-Seligmann G, Rotem-Galili Y, Mirelman A, Dickstein R, Giladi N, Hausdorff JM. How does explicit prioritization alter walking during dual-task performance? Effects of age and sex on gait speed and variability. *Phys Ther*. 2010;90:177–186.
84. Clark DJ. Automaticity of walking: functional significance, mechanisms, measurement and rehabilitation strategies. *Front Human Neurosci*. 2015;9.
85. Lord S, Rochester L, Weatherall M, McPherson K, McNaughton H. The effect of environment and task on gait parameters after stroke: a randomized comparison of measurement conditions. *Arch Phys Med Rehabil*. 2006;87:967–973. http://www.archives-pmr.org/article/S0003-9993(06)00281-4/pdf
86. Terwee CB, Mokkink LB, Knol DL, Ostelo RW, Bouter LM, de Vet HC. Rating the methodological quality in systematic reviews of studies on measurement properties: a scoring system for the COSMIN checklist. *Qual Life Res*. 2012;21:651–657.
87. Chatterjee SA, Daly JJ, Porges EC, Fox EJ, Rose DK, McGuirk TE, et al. Mobility function and recovery after stroke: preliminary insights from sympathetic nervous system activity. *J Neurol Phys Ther*. 2018;42:224–232.