

REVIEW

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Advancing standardisation of motor-cognitive dual task walking assessments: a scoping review of methodological practices in healthy older adults

Sharon Olsen^{1*}, Ruth McLaren¹, Aidan Scrooby¹, Nusratnaaz Shaikh¹, Dion Henare¹, Denise Taylor^{1,2} and Shikha Chaudhary¹

Abstract

Background Dual task (DT) assessments evaluating walking combined with a cognitive task are valuable tools for testing functional capacity and monitoring age-related decline. Despite this, motor-cognitive DT assessments are underutilised in clinical practice. This has been attributed in part to methodological challenges, including heterogeneity in DT measurement protocols and poor reliability of outcome measures. To address these barriers, this scoping review systematically identified motor-cognitive DT walking assessments used with healthy older adults and examined current practice in reporting and standardisation. The purpose was to inform the refinement of DT assessments to enhance their precision and reproducibility, facilitating their future integration into routine clinical practice.

Method A systematic search of five electronic databases identified studies that investigated motor-cognitive DT walking assessments in community-dwelling, cognitively healthy older adults. The reporting and standardisation of measurement procedures was extracted using the COSMIN framework. The findings were analysed descriptively.

Results The review included 38 studies investigating a walking motor task combined with a variety of cognitive tasks. The most common walking tasks were unidirectional gait, the timed up and go (TUG), or walking and turning tasks. The most prevalent cognitive tasks included serial subtraction, animal naming, and reciting alternate alphabet letters. There was substantial variability in the administration of DT assessments and no studies fully reported the procedures for set up, test performance, and data collection. Of particular concern was the poor reporting of general task instructions, task prioritisation, and practice trials.

Conclusion The review identified a lack of standardisation in DT walking measurement procedures, which likely contributes to measurement variability and limits clinical replication. Given that measurement variability inherent in single task assessments is compounded when motor and cognitive tasks are combined, it is critical to address these sources of inconsistency to ensure DT measures detect and accurately reflect true performance changes.

*Correspondence:

Sharon Olsen
Sharon.Olsen@aut.ac.nz

Full list of author information is available at the end of the article



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Recommendations are made to improve standardisation of DT measurements with the aim of facilitating their broader adoption and implementation in clinical practice.

Keywords Dual task, walking, gait, motor-cognitive, older adult, measurement variability

Introduction

The ageing process is accompanied by a spectrum of degenerative motor, sensory, and cognitive changes [1] that heighten older adults' predisposition to physical frailty, injuries, and falls [2]. The adverse impacts of ageing are exacerbated by the increasing proportion of elderly individuals in the population, presenting a notable economic and societal challenge [2]. Consequently, healthcare strategies have emerged with a focus on fostering 'healthy ageing' to preserve functional capacity throughout an extended life span [2, 3]. A pivotal aspect of this approach is the development of valid and reliable indicators that can detect and monitor age-related decline, and facilitate the implementation of interventions that could minimise deterioration [3].

One marker of age-related decline is difficulty performing dual motor-cognitive tasks, wherein two tasks are performed concurrently, such as walking while counting backward [4]. The ageing process imposes an increased demand on attention during walking [5], coupled with a slowing in cognitive function [6]; this results in altered performance of one or both tasks [7], a phenomenon termed dual-task effect (DTE) or dual task cost. Previous systematic reviews investigating motor-cognitive DTE during walking in older adults have shown differences between fallers and non-fallers [8], as well as the potential to predict falls [8–10]. Furthermore, motor-cognitive DTE during walking has shown potential to predict future cognitive impairment [11]. Research has demonstrated correlations between motor-cognitive DT measures and established measures of balance and mobility or cognitive impairment [4, 12–15], however, the strength of correlation is weak to moderate. This suggests that while DT measures capture aspects of performance related to their individual motor and cognitive components, there may be other factors beyond balance, cognition and mobility alone that influence performance. Accordingly, DT assessments appear to offer additional value over single task walking assessments [8], supporting their potential for inclusion in clinical assessment of age-related changes.

The incorporation of DT performance and measurement into clinical practice remains infrequent, due to several factors. Firstly, previous systematic reviews have emphasised that heterogeneity in measurement and protocols compromises the ability to meta-analyse the data [9, 10, 16], therefore definitive recommendations for implementation of these measures in clinical practice cannot be made. Secondly, systematic reviews have

demonstrated that the reliability of DTE measurements is poor [4, 17], thereby limiting their precision in accurately identifying individuals with impairment. Furthermore, prior research examining clinically feasible DT measures such as the DT Timed Up and Go (TUG) indicates that motor performance metrics (e.g., completion time) under DT conditions show high reliability, while cognitive performance metrics (e.g., digits recalled, number of animals named) tend to exhibit poor to moderate reliability [18, 19]. This variability underscores the need to identify sources of poor reliability, including variability in task performance, task priorities, task difficulty, and the underlying cognitive functions being tested [4, 20]. Thirdly, the interpretation of DTE measures is challenging [20]. For instance, a reduction in walking speed whilst performing a DT involving walking and subtracting in threes could stem from factors such as the attentional demands of the cognitive task, prioritisation of the cognitive task, or a loss of gait automaticity [20].

Currently, there are no standardised clinical measures of walking motor-cognitive DTE that provide a protocol addressing sources of measurement variability and providing explicit guidance on result interpretation. Although numerous reviews have examined the validity or reliability of DT measures [4, 8–10, 17], there has not been a comprehensive literature review that explores and summarises potential sources of measurement error and variability in motor-cognitive DT walking measurements in older adults. Such work is essential to guide future standardisation efforts and improve validity and reliability. Therefore, the objectives of this scoping review were to:

1. Identify and chart the range of motor-cognitive dual-task walking measurements that have been investigated in community-dwelling older adults without cognitive impairment, and
2. Explore the reporting and standardisation of measurement characteristics that may support or limit their accurate and precise replication in clinical practice.

Method

Study design

A scoping review method was selected to systematically identify and chart relevant literature on the topic, describe its characteristics, and identify evidence gaps [21].

Protocol registration

The protocol was drafted using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Extension for Scoping Reviews [22], and then revised by the research team. The final protocol was registered on the Open Science Framework [23].

Search strategy

A systematic search was undertaken in the following databases: MEDLINE/SPORTDiscus/CINAHL via EBSCO, Scopus and AMED. Search terms related to four categories: community-dwelling older adults, cognitive-motor dual tasks, walking, and psychometric properties (see search strategies in Supplementary File 1). In addition, relevant systematic reviews were hand searched to

ensure no primary studies included in those reviews were missed in the search. The search was conducted from database inception and was last updated on 26th May 2024. Findings from all databases were exported to End-Note, where duplicates were eliminated, and a further exportation to Rayyan software was undertaken.

Selection of evidence

The eligibility criteria are provided in Table 1. Initial scoping had revealed a large volume of studies employing DT measures, making a full review of all study designs infeasible. Furthermore, a notable proportion of intervention, descriptive, or group-comparison studies included DT tests, but provided minimal procedural detail, limiting their utility for addressing objective 2. Therefore, to balance search breadth with practicality—a key consideration in scoping reviews [24, 25]—the review focused on studies investigating psychometric properties, as these were most likely to provide detailed descriptions of DT measurement procedures. Accordingly, inclusion was limited to study designs investigating validity (convergent, discriminative, or predictive) or reliability. Initially, studies were required to use a DTE measure, however, in line with scoping review methodology [21], the eligibility criteria were refined to also include measures of DT performance, due to the limited volume of DTE literature.

Title and abstract screening were conducted independently by two reviewers (SO and AS, SO and SC). Any discrepancies were resolved through comparison and discussion with a third reviewer if required. Subsequently, full texts were evaluated through the same process, by pairs of independent reviewers (SO and AS, NS and SO, NS and AS). The team met regularly to discuss criteria and resolve disagreements.

Data charting process

A data charting form was developed by three reviewers (RM, SO, and SC) and refined by the research team. This included the following characteristics: study design, type of validity or reliability investigated, aim, sample characteristics, sample size, single walking task characteristics and measurement parameters, single cognitive task characteristics and measurement parameters, dual task characteristics and measurement parameters, comparison clinical measure (for convergent validity), and relevant findings.

The Consensus-based Standards for the selection of health Measurement Instruments (COSMIN) initiative developed a framework to identify sources of measurement variability that should be considered when designing a reliability study (part A of the COSMIN risk of bias tool) [26]. This guidance was considered more useful than that the COSMIN quality assessment tool (Part B of the tool) [26], which only has one question focused on

Table 1 Eligibility criteria

	Inclusion	Exclusion
Participants	Community-dwelling, cognitively healthy older adults (≥ 60 years).	Diagnosed neurological, orthopaedic, or other medical conditions that may affect balance and mobility. Mixed populations (healthy and unhealthy), unless healthy group analysed independently.
Measurements	Measures a motor-cognitive DT paradigm involving a primary gait task and secondary cognitive task. Reports DT cost or DT performance, for either gait or cognitive performance. Reports performance metrics for the single task used in the DT paradigm.	DT motor task involving stepping in place, gait initiation, balance in quiet stance, or stair walking. DT involving two motor tasks.
Investigation	To identify a subgroup of studies most likely to describe DT measurement procedures, studies needed to investigate any of the following psychometric properties of the DT measurement: i) convergent validity compared with another non-DT measure of gait, standing balance or cognition, ii) discriminative validity between fallers and non-fallers, iii) predictive validity for future balance or cognitive function, or iv) reliability.	Investigations that: make comparisons between DT measure and single task from same DT paradigm; analyse between-group differences without investigating validity; analyse effectiveness of an intervention on the ability to dual task.
Study design	Primary research; observational studies or baseline data from experimental studies.	Review articles, case reports and expert opinions.
Publication	Full text peer-reviewed journal articles published in English.	Abstract only papers, theses and dissertations.

measurement procedures. Part A of the COSMIN framework was used to develop the charting form for extracting data related to sources of error or inconsistency in the application of DT measurements. Additional detail was added to this data extraction framework to specify details relevant to DT assessment. The key components included: equipment, equipment calibration and set up, preparation of environment, preparation of patient by the professional, preparation undertaken by patient, required expertise, general instructions, task prioritisation instructions, practice trials, how tasks were performed, method for collecting raw data, number of recorded trials, methods for handling data, and methods for translating raw data into scores or metrics. Data was extracted from the primary article and any referenced articles that the authors identified as containing the methodological procedures that were followed. All data extraction was completed by pairs of independent reviewers (SO and SC, RM and NS) and checked for accuracy by SO. Any queries were discussed with the research team.

Analysis

To meet the first review objective, studies were grouped according to their aim (convergent validity, discriminative validity, predictive validity, reliability) and their measurement properties (non-instrumented, instrumented) and study characteristics were described. In addition, dual task characteristics were explored descriptively and figuratively.

To meet the second review objective, the data related to sources of measurement error or variability were quantified and described to provide an overview of DT measurement characteristics and procedures that either increase or decrease variability.

Results

Study selection

The review included 40 articles and 38 study populations. See Fig. 1 for PRISMA flowchart.

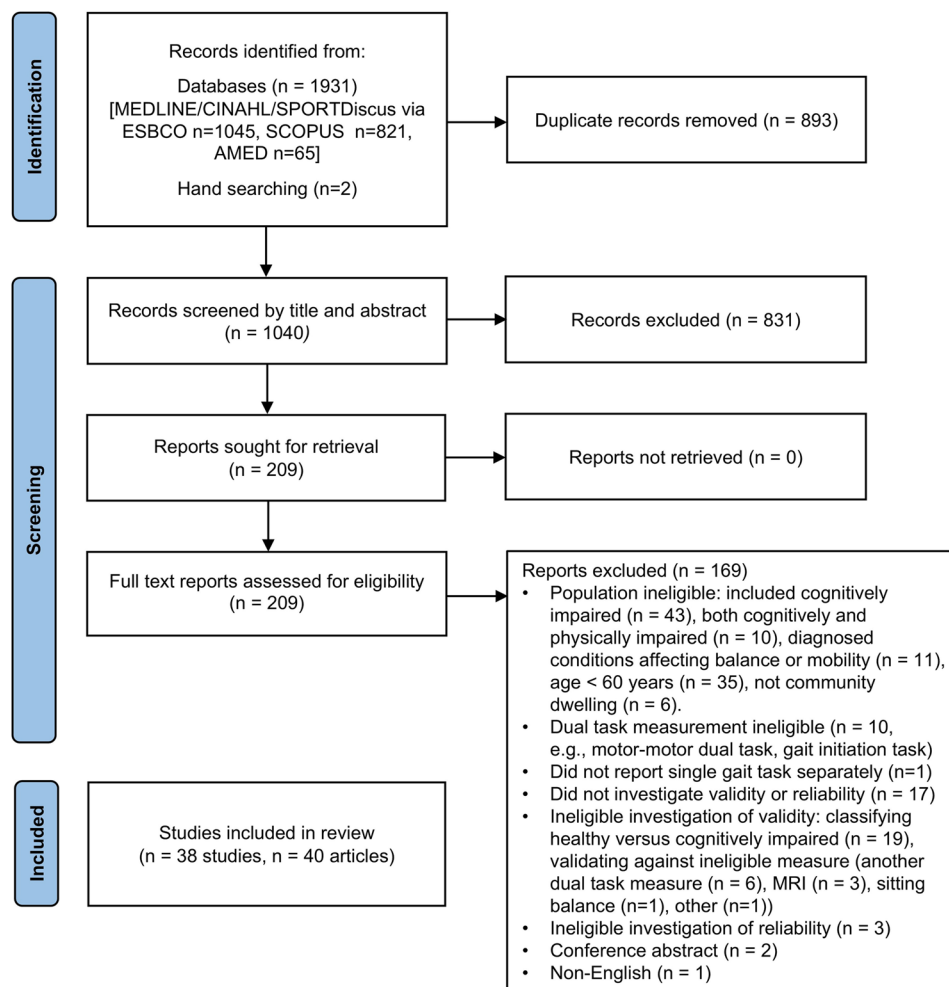


Fig. 1 PRISMA flowchart

Study characteristics

The study characteristics including aims, populations, measurements, and findings can be seen in Supplementary File 2. The methods used to carry out DT testing can be found in Tables 2 and 3, for studies that used instrumented, and non-instrumented measures, respectively.

Across the 38 included studies, sample sizes ranged from 12 to 367 individuals, and the mean age was typically between 65 and 80 years. Most studies included a higher proportion of female participants, with several studies being female-only. As per the inclusion criteria, all included studies investigated cognitively-healthy, community-dwelling older adults, however, the assessment of cognitive function varied. The majority of studies ($n=14$) assessed cognitive status using the Mini-Mental State Examination (MMSE). Other tools employed included the Montreal Cognitive Assessment (MoCA), Trail Making Test, and Digit Span Test. In several studies, cognitive status was determined through self-report or inferred from the absence of documented cognitive impairment. Regarding mobility, inclusion criteria commonly required participants to ambulate independently without the use of assistive devices.

Of the 38 included studies, 17 studies employed cross-sectional designs to examine associations between DT measures and other clinical measures of cognitive or walking/balance function. Six studies assessed whether DT measures could discriminate between fallers and non-fallers, and eight studies employed longitudinal designs to investigate whether DT measures could predict future falls. Ten studies focused on the reliability of dual-task gait testing.

Motor-cognitive DT walking measurements used in healthy older adults (Objective 1)

As seen in Tables 2 and 3, the included articles described and tested a range of motor-cognitive DT walking measurements that have the potential to be used to assess or monitor age-related changes.

Dual task characteristics varied significantly across the included studies. The range of motor and cognitive components can be seen in Fig. 2. The most common motor tasks were: unidirectional walking, TUG, walking and turning, and walk and return tests. The most common cognitive tasks were: serial subtractions, reciting alternate alphabet letters (grouped under “updating tasks” in Fig. 2), and naming animals (grouped under “verbal fluency” in Fig. 2). Most dual tasks included two distinct components that were combined. However, one study used integrated motor-cognitive tasks, where the performance of both tasks was interdependent [27], and one study used a cognitive task where the memorising component was carried out during the walking task, but the recall was required after the walking task [28].

The methods used to calculate DTE varied and are summarised in Table 4. The majority of studies used relative or absolute DTE calculations dating back to at least the 1980s.

Standardisation of measurements and potential sources of variability (Objective 2)

This section will explore measurement characteristics of the included studies, to inform a discussion of factors that may support or limit the accurate and precise replication of DT measures in clinical practice. Measurement characteristics including single and DT descriptions, task instructions, and DT measurement parameters are provided in Tables 2 and 3, and further information about equipment requirements, preparation, testing protocols and recording procedures, are provided in Supplementary File 3 (Table 2s and 3s). No studies fully reported the procedures for set up, performing the DT test, and collecting data. Reporting of standardised procedures was not notably different for the 10 articles that analysed reliability compared with the remaining 30 articles that investigated validity only.

Expertise and training

Across all included articles, only three studies described the expertise or training of assessors [31, 35, 52].

Recording devices

Of the studies that used instrumented measurements, 20 out of 22 studies specified the recording device for motor DT performance: these were pressure-sensitive walkways ($n=10$), wearable sensors ($n=1$), combination of sensors ($n=3$), treadmill sensors ($n=2$), TUG cushion ($n=1$), and insoles not further specified ($n=3$). However, for studies that used non-instrumented measurements, only 10 of 16 studies reported the motor recording device; these included stopwatch use ($n=8$), video ($n=1$), and an FGA chart ($n=1$). Of the 8 studies that measured cognitive DT performance, only four reported the recording device (auditory recorder $n=2$ [15, 57], video $n=1$ [60], computer application $n=1$ [50]).

Additional equipment

In general, where additional equipment was required for the test, this was described. Only four studies did not describe additional equipment that was required such as a chair for the TUG [13, 48] or equipment to mark the walking route [12, 58]. A further two studies did not provide sufficient details about the equipment required for delivering cognitive cues [28, 45].

Preparation of environment and patient

Most studies (13 out of 16 non-instrumented studies and 17 out of 22 instrumented studies) provided information

Table 2 Instrumented DT measurement protocols

Author	Brief dual task name	Single task description	Dual task description	Instructions reported	DT measures
Instrumented timed up and go (TUG)					
Smith et al. (2016) [29]	TUG + serial subtractions (3s)	Motor: TUG (described)	DT TUG while counting backwards in 3s from random 3-digit number	<i>General:</i> Asked to stand up walk 3 m as quickly as they could to a mark in the floor, turn and return to the chair while subtracting 3 loudly from a random 3-digit number. No instructions given about how to turn <i>Prioritisation:</i> No instructions given on which task to prioritise	- 21 digital gait parameters
Tong et al. (2023) [30]	TUG + serial subtractions (3s)	Motor: TUG (protocol described)	DT TUG while counting backwards in 3s from a randomly selected number between 40 and 100	<i>General:</i> Asked to stand up from a chair, walk 3 m as comfortably and safely as possible in their usual gait, cross a line marked on the floor, turn around, walk back, and sit down. Instructed to complete the test at a comfortable and safe pace, which was closer to a real-life situation. Cog instructions NR <i>Prioritisation:</i> NR	- Digitally timed task
Pressure sensing and accelerometers					
Beauchet et al. (2011) [31]	Walking + counting backwards	Motor: Walk alone at self-selected speed	DT walking while counting backward aloud starting from 50	<i>General:</i> Standardised verbal instructions regarding test procedure. Not provided <i>Prioritisation:</i> No prioritisation of walking or cog task	- Digital gait parameters
Bruce-Keller et al. (2012) [32]	Walking + spelling backwards	Motor: Walk at preferred speed	DT walking while spelling common 5-letter words backwards. Words selected randomly from a 45-word list, unique word for each trial. Words verbalised as participant crossed threshold	<i>General:</i> Perform 3 walkway crossings for the specified walking task, with rest as needed in between. For the DT, "please spell [5-letter word] backwards" <i>Prioritisation:</i> NR	- Digital gait parameters
Caetano et al. (2018) [33]	Walking while: (i) avoiding obstacles, (ii) stepping on near targets, (iii) stepping on further targets, (iv) receiving no stimuli. All done with serial subtractions	Motor: Walk while: (i) avoiding stepping on pink light appearing 2 steps ahead, (ii) stepping on green light appearing slightly short of 2 steps ahead, (iii) stepping on green light appearing slightly further than 2 steps ahead, (iv) no stimulus. Target presented 3rd heel strike	Single task conditions combined with counting backwards by 3s from a random 2-digit number	<i>General:</i> Instructed to step in the middle of the targets (green light) and to avoid stepping on the obstacle (pink light), being free to use any avoidance strategy. Start walking with right foot in all conditions. Cog instructions NR <i>Prioritisation:</i> NR	- Motor errors (stepping on obstacle, missing target) - Velocity recorded digitally
Comman-deur et al. (2018) [34]	Walking + serial subtractions (7s)	Motor: Walk at preferred walking speed	DT walking while counting backward by serial 7s aloud from a randomly generated 3-digit number	<i>General:</i> Asked to walk at a self-selected preferred walking speed along walkway. Cog instructions NR <i>Prioritisation:</i> NR	- Digital gait parameters - DTE (difference) = DT - ST
Gabel et al. (2015) [35]	Narrow walking + reciting alt letters or counting backwards	Motor: Walk between lines, length of mat at normal pace, turn around, return to starting point	DT narrow walking while reciting alt letters from either a or b; or counting backwards by twos, from either 95 or 94	<i>General:</i> Stay between the lines while performing the tasks. Other NR <i>Prioritisation:</i> Pay special attention to correctly perform the cognitive task, even at the expense of normal walking speed	- Digital gait parameters - DTE CV = DT CV - ST CV / ST CV
Gillain et al. (2019a) [36]; Gillain et al. (2019b) [37]	Walking + serial subtractions (7s)	Motor: Walk along walkway comf speed (also recorded fast speed, but not used in DTE)	DT walking while counting backward by serial 7s from 100	<i>General:</i> Walk at a comfortable walking speed while simultaneously making arithmetic (seven counting down since the number 100) <i>Prioritisation:</i> "make both tasks simultaneously and as well as you can"	- Digital gait parameters - DTE = (Comf ST - DT) / Comf ST × 100

Table 2 (continued)

Author	Brief dual task name	Single task description	Dual task description	Instructions reported	DT measures
Herman et al. (2010) [38]	Walking + serial subtractions (3s)	<i>Motor:</i> Walk up/down hallway for 2 min at usual preferred speed	DT walking while subtracting serial 3s from a predefined 3-digit number	<i>General:</i> NR <i>Prioritisation:</i> Without explicit instructions regarding prioritisation	- Digital gait parameters
Hollman et al. (2010) [39]	Walking + spelling backwards	<i>Motor:</i> Walk self-selected pace	DT walking while verbally spelling 5-letter word backward (taken randomly from 45-word list). Word verbalised as subjects crossed threshold	<i>General:</i> NR <i>Prioritisation:</i> NR	- Digital gait parameters
Howcroft et al. (2016) [40]	Walking + naming words starting with certain letter	<i>Motor:</i> Walk 7.62 m. Walking pace NR	DT walking while saying words starting with A, F, or S. Starting letter randomised. Walking pace NR	<i>General:</i> NR <i>Prioritisation:</i> NR	- Digital gait parameters - Timed task (s)
Howcroft et al. (2017) [41]; Howcroft et al. (2018) [42]	Walking + naming words starting with certain letter.	<i>Motor:</i> Walk 7.62 m. Walking pace NR	DT walking while saying words starting with A, F, or S. Starting letter randomised. Walking pace NR	<i>General:</i> NR <i>Prioritisation:</i> NR	- Digital gait parameters
Kim et al. (2017) [43]	Walking + counting forward in 3s	<i>Motor:</i> Walk on walkway at comf pace	DT walking while counting forward from 2-digit number in 3s	<i>General:</i> Asked to walk at their comfortable speed along a 6 m walkway, then, perform the additional task simultaneously. Further instructions for cog tasks NR <i>Prioritisation:</i> No instruction for prioritisation of one task	- Step length (m) (assumed digital) - Walking speed (m/s) - DTE = (ST - DT)/ST × 100
Kirby et al. (2021) [44]	Walking + spelling backwards	<i>Motor:</i> Walk on walkway at normal everyday speed	DT walking while spelling a word backward aloud. Words for cog DT were from a list in GAITRite manual	<i>General:</i> Instructed to walk across the walkway "using their normal everyday walking speed." For DT, instructed to spell a word backward aloud while walking <i>Prioritisation:</i> NR	- Digital gait parameters - DTE (hit) = % difference between ST and DT
Lara et al. (2024) [45]	(i) Walking + responding to questions (e.g. name 4 fruits, words with a specific letter), (ii) Walking around obstacles while memorising and reciting number series	<i>Motor:</i> Walk on walkway at comf self-selected speed. Walk 3 laps of walking circuit avoiding and stepping over obstacles (diagram provided)	(i) DT straight walking while answering questions as quickly as possible. 31 questions of varying difficulty (i.e. naming animals, words with a specific letter) but specifics NR. 3s for question, 7s to answer. (ii) DT obstacle walking while memorising/repeating number series indicated in digit span test. Time for response = time for statement	<i>General:</i> NR <i>Prioritisation:</i> Instructed not to prioritise either the walking or the cognitive task	- Digital gait parameters - Timed task (s) - DTE = (DT - ST)/ST × 100
Mirelman et al. (2012) [46]	Walking + serial subtractions (3s)	<i>Motor:</i> Walk up and down hallway for 2 min at self-selected speed	DT walking while subtracting serial 3s from a predefined 3-digit number	<i>General:</i> NR <i>Prioritisation:</i> NR	- Digital gait parameters
Nordin et al. (2010) [47]	(i) Walking + naming animals, (ii) Walking + serial subtractions	<i>Motor:</i> 2 ST walks each at slow, normal, and fast speed	DT walking at normal speed while (i) naming as many different animals as possible, (ii) serial subtractions in 3s starting number randomly selected from either 50, 55, 60, or 65, and not given until the task was fully understood, and just prior to starting	<i>General:</i> Instructions provided for slow, normal, and fast ST walks. DT: "Walk at your normal/usual speed while you simultaneously..." verbally enumerate as many different types of animals as possible" or "perform serial subtractions by 3s starting from 50 and counting out loud" <i>Prioritisation:</i> NR	- Digital gait parameters - ST plotted on curvilinear graph. DTE was difference between DT value minus curve value at same speed.

Table 2 (continued)

Author	Brief dual task name	Single task description	Dual task description	Instructions reported	DT measures
Springer et al. (2006) [28]	(i) Walking + listening to auditory text, then answer 10 MCQs, (ii) Walking + listening and counting prespecified words, then answer 10 MCQs, (iii) Walking + serial subtractions	<i>Motor</i> : Walk up and down hallway at self-selected, usual walking speed for 2 min <i>Cog</i> : Listen on headphones and afterwards answer 10 MCQs, in sitting	DT walking while: (i) simple task – listening on headphones and afterwards answering 10 MCQs, (ii) complex – listening and counting prespecified words, then 10 MCQs related to content and prespecified words, (iii) serial 7s, recited out loud from 500. Content of auditory text and MCQs NR	<i>General</i> : Instructions were to walk at a comfortable pace and to perform the additional dual task. Cog task instructions NR <i>Prioritisation</i> : No instruction for priority of one of the tasks	- Digital gait parameters
Venema et al. (2019) [48]	(i) Walking + counting forward, (ii) Walking + serial subtractions, (iii) TUG + counting forward, (iv) TUG + serial subtractions	<i>Motor</i> : 6 m walk in straight line at self-selected walking speed. TUG referenced.	DT straight walking while: (i) counting forward by ones from random number between 10–20, (ii) serial subtractions in 3s from a random number between 70–90. DT TUG while: (iii) counting forward by ones, and (iv) serial subtractions in 3s. Different starting numbers used for counting tasks	<i>General</i> : NR. Set script. <i>Prioritisation</i> : No instruction given on task prioritisation	- Digital gait parameters - Timed TUG - DTE = (difference in DT and ST performance/ST performance) ×100
Treadmill					
Ehlers et al. (2017) [49]	Virtual street crossing + talking on cell phone	<i>Motor</i> : Virtual crossing street on treadmill (90s to complete trial)	Virtual street crossing while talking to researcher on hands-free cell phone. Details of conversation NR (i.e. cog load)	<i>General</i> : Instructed to safely cross a virtual street. Instructions for cog task NR <i>Prioritisation</i> : NR	Dual-task success ratio (# successful trials / # total trials)
Szturm et al. (2017) [50]	(i) Treadmill walking + visuomotor tracking task, (ii) Treadmill walking + visuospatial game	<i>Motor</i> : Walking on treadmill at 0.9 m/s <i>Cog</i> : Visuomotor tracking task (45 s) using head motion to align 2 objects on screen. Visuospatial game (60–67.5 s) using head motion to move a paddle to interact with moving objects. In standing	(i) DT treadmill walking with visuomotor task (ii) DT treadmill walking with visuospatial game	<i>General</i> : NR. <i>Prioritisation</i> : NR	- Digital gait parameters - Digital cognitive parameters
Wolleson et al. (2017) [51]	Treadmill walking + Stroop test	<i>Motor</i> : 30 s walking at self-selected constant speed	DT treadmill walking with visual Stroop test comprised 16 events of incongruent colour words. Participants had to name colour and inhibit reading word	<i>General</i> : Standardised introduction to test and had to name the colour of letters and refrain from reading the word <i>Prioritisation</i> : No advice for task prioritisation	- Digital gait parameters

3s three, 7s sevens, *alt* alternating, *cog* cognitive, *comf* comfortable, *CV* coefficient of variance, *DT* dual task, *DTE* dual task effect, *m* metres, *MCQ* multiple choice question, *NR* not reported, *s* second, *ST* single task, *TUG* Timed Up and Go, # number

about preparation of the environment such as lines or marks on the floor, placement of equipment such as cones, furniture, lighting, obstacle set up, cameras, quiet space, virtual environment, and cognitive stimuli (see Supplementary File 3).

For preparation undertaken for or by the patient, only two of the 16 (13%) non-instrumented studies reported the footwear worn during testing [52, 60] in comparison to 9 out of 22 instrumented studies (41%) (see Supplementary File 3).

Description of single and dual tasks

Of the 38 studies, 28 (74%) completely described the performance of single and dual tasks. Missing details from the other 10 studies included the pace of the DT [27] or both tasks [40–42], starting point when reciting letters [14], details of the cognitive task that would enable replication [28, 45, 49, 57], methods for combining the cognitive task with the motor tasks [62], and whether the protocol of the previous study by the same authors was explicitly followed [58].

Table 3 Non-instrumented DT measurement protocols

Author	Brief dual task name	Single task description	Dual task description	Instructions reported	DT measures
Timed up and go (TUG)					
Ansai et al. (2018) [52]	DT TUG + phone number dialling	<i>Motor:</i> TUG at usual speed <i>Cog:</i> Dialling phone numbers from a card (seated)	DT TUG while dialling numbers from card. (New card drawn between ST and DT)	<i>General:</i> ST TUG: Standardised instructions, at usual speed. <i>Cog</i> task: While "seated, pick up the phone, dial the numbers on this card and place the phone on the table. Ready, Go". DT TUG: "You will get up, pick up the phone, dial the numbers of the card while making the course, place the phone and sit down. Ready, go" <i>Prioritisation:</i> NR	- Timed task (s). - Correct hits/s.
Borges et al. (2018) [13]	DT TUG + animal naming	<i>Motor:</i> TUG (protocol described)	DT TUG while naming as many animals as possible	<i>General:</i> "Stand up from a chair, walk 3m at comfortable speed, cross a line on the floor, turn around, walk back, and sit down". Then "do it while naming as many animals as you can remember". Then "do it as you hold this cup of water and name as many animals as you can remember" <i>Prioritisation:</i> NR	- Timed task (s). - # animals. - Motor DTE = (DT TUG minus ST TUG)/100.
Hofheinz & Schuster-schitz (2010) [53]	DT TUG + serial subtractions (3s)	<i>Motor:</i> TUG (protocol described)	DT TUG while counting backwards in 3s from 100. Started from various points, 100/90/80/70	<i>General:</i> "Walk as quickly and safely as possible to the marked line, turn through 180°, walk back to the chair, turn through 180° and sit down again. In addition, count as quickly and surely as possible backwards in 3s from 100. Do not repeat the number you are told to start from, but start with the first result you calculate." "Get ready, go!" <i>Prioritisation:</i> NR	- Timed task (s). - # of 'counting steps'
Hofheinz & Miibs (2016) [54]	DT TUG + serial subtractions (3s)	<i>Motor:</i> TUG (protocol described)	DT TUG while counting backwards in 3s from 100. Started from random number between 60 and 100	<i>General:</i> "Walk as quickly and safely as possible to the marked line, turn through 180°, walk back to the chair, turn through 180° and sit down again. In addition, count as quickly and surely as possible backwards in 3s from 100. Do not repeat the number you are told to start from, but start with the first result you calculate." "Get ready, go!" <i>Prioritisation:</i> NR	- Timed task (s)
Shumway-Cook et al. (2000) [55]	DT TUG + serial subtractions (3s)	<i>Motor:</i> TUG protocol described. Used walking aid if they used one in the community	DT TUG while counting backward by 3s from randomly selected number	<i>General:</i> Stand up from a chair, walk 3 m as quickly and as safely as possible, cross a line marked on the floor, turn around, walk back, and sit down. Then complete the test while counting backward by 3s from a randomly selected number between 20 and 100. <i>Prioritisation:</i> NR	- Timed task (s). - DTE (difference) = DT TUG - ST TUG
Tomas-Carus et al. (2019) [56]	DT TUG + counting backward in ones	<i>Motor:</i> TUG protocol described	DT TUG while counting backwards by ones from 100	<i>General:</i> "Walk as quickly and safely as possible to the marked line, turn through 180°, walk back to the chair, and sit down again. In addition, count as quickly and surely as possible backward by 1 from 100. Get ready, go!" <i>Prioritisation:</i> NR	- Timed task (s) - # motor stops - # cog errors/stops - TUG DTE = (DT - ST / mean both)

Table 3 (continued)

Author	Brief dual task name	Single task description	Dual task description	Instructions reported	DT measures
Walk and return					
Hall et al. (2011) [15]	(i) WWT + alphabet, (ii) WWT + alt alphabet letters, (iii) Functional Gait Test + serial subtractions, (iv) Functional Gait Test + naming words	<i>Motor:</i> Walk, turn and return (WWT, 6.1 m), Functional Gait Test (unidirectional 6.1 m). <i>Cog:</i> Reciting alphabet aloud, reciting alt alphabet letters (from A), counting backward by 3s, from different random number, naming words starting with particular letter, in 1 min	(i) WWT while reciting alphabet, (ii) WWT while reciting alt alphabet letters (from B), (iii) Functional Gait Test with serial subtractions in 3s, (iv) Functional Gait Test while naming words. Different letters for each trial	<i>General:</i> All gait tasks performed at participants preferred speed. No other instructions specified <i>Prioritisation:</i> Pay equal attention to cognitive and walking tasks	- Timed task (s) - Correct response rate - Motor DTE = (DT time – ST time)/ST time - Cognitive DTE = (ST CRR – DT CRR)/ST CTT)
Liu-Am-brose et al. (2009) [12]	(i) WWT + reciting alphabet, (ii) WWT + reciting alt alphabet letters	<i>Motor:</i> Walk, turn and return (WWT, 20ft)	(i) Simple WWT while reciting consecutive letters aloud (i.e., a, b), (ii) Complex WWT while reciting alt letters (i.e., a, c)	<i>General:</i> Instructed to walk an outlined route of 20 ft, turn, and return 20 ft to the starting position. Instructions for cognitive tasks NR <i>Prioritisation:</i> Be as accurate as possible when performing the cognitive task	- Timed task (s)
Muhaidat et al. (2013) [57]	(i) Walking + clock task, (ii) Walking with turns + serial subtractions, (iii) Walking with turns + naming animals, (iv) Walking around obstacles + naming animals, (v) Stair descent + naming animals, (vi) WWT + reciting alt letters	<i>Motor:</i> Straight walk 10 m. Walk with turns (3 m walk with two 180° turns). Walk while avoiding obstacles (chair, ray of light). Descending 4 steps. WWT with turn at 6.1 m <i>Cog:</i> Clock task (deciding if 2 hands of imaginary clock are on same side). Serial subtraction in 3s started from random 3-digit number. Animals/letters methods NR	(i) Walking with clock task, (ii) Walking with turns with serial subtractions, (iii) Walking with turns while naming animals, (iv) Walking while avoiding obstacles and naming animals, (v) Stair descent while naming animals, (vi) Walking with turns (WWT) while reciting letters	<i>General:</i> Instructed to walk at preferred speed. Instructions for cog tasks NR <i>Prioritisation:</i> Instructed to perform both tasks as well as possible	- Timed task (s) - # answers/s - # errors/s - Motor DTE = (ST time – DT time)/ST time x 100 - Cog DTE = ST – DT
Muhaidat et al. (2014) [58]	As for Muhaidat et al. (2013) (57)	As for Muhaidat et al. (2013) but NR if previous protocol followed	As for Muhaidat et al. (2013) but NR if previous protocol followed	<i>General:</i> Instructed to walk at preferred speed. Instructions for cog tasks NR <i>Prioritisation:</i> Instructed to perform both tasks as well as they could	As for Muhaidat et al. (2013)
Niermeyer & Suchy (2020) [59]	DT walk and return avoiding obstacles + serial subtractions (3s)	<i>Motor:</i> Walk across room and back while avoiding 8 cardboard strips at comf pace	Walking while avoiding obstacles and counting backwards by 3s (different number provided at start of each trial)	<i>General:</i> Instructed to walk at a comfortable pace. Instructions for starting, turning, and cog tasks NR <i>Prioritisation:</i> No explicit instructions regarding task prioritisation	- Timed task (s)
Unidirectional walking					
Ghanavati et al. (2018) [14]	DT walking + reciting alt letters	<i>Motor:</i> Walk 20 m in long corridor at usual speed	Walking while reciting alt letters of alphabet. Alphabet start point NR	<i>General:</i> Asked to walk 20 m at their usual (self-selected) speed under ST and DT conditions in a long corridor. Reminded to keep walking for the full 20 m. Instructions for cog task NR <i>Prioritisation:</i> Be as accurate as possible when performing the cognitive task	- Timed task (s)

Table 3 (continued)

Author	Brief dual task name	Single task description	Dual task description	Instructions reported	DT measures
Gimmon et al. (2016) [60]	DT narrow walking + (i) reciting weekdays backward, (ii) reciting months backward, and (iii) counting backwards in 5s	<i>Motor</i> : Walk at comf pace within narrow path <i>Cog</i> : Reciting days of week backwards, reciting months of the year backwards, and counting down in increments of 5 from 100	DT narrow walking while: (i) reciting days of week backward, (ii) reciting months of year backward, and (iii) counting backwards in 5s from 100	<i>General</i> : Instructed to walk at a preferred walking speed within a 6 m long narrow path under ST and DT conditions. For ST, specified walking without stepping outside the narrow path. Instructions for cog task NR <i>Prioritisation</i> : Asked to perform both tasks as best as they can	- # steps - Timed task (s) - velocity (m/s) - # step errors - # cognitive errors
Liu et al., 2024) [61]	(i) DT walking on even surface + reciting alt letters, (ii) DT walking on uneven surface + reciting alt letters.	<i>Motor</i> : Walk on even surface at comf pace <i>Cog</i> : Reciting alt alphabet letters starting from B, in standing for 20s	(i) Easy DT walking on even surface while reciting alt letters. (ii) Hard DT walking on uneven surface while reciting alt letters	<i>General</i> : NR <i>Prioritisation</i> : No instructions given about which task to prioritise	- Gait speed m/s. - Correct letters/s. - Performance Δ = (motor DT-ST/motor ST) + (cognitive DT-ST/cognitive ST)
Sulaiman et al. (2020) [62]	(i) FGA + numeracy tasks (ii) FGA + literacy tasks	<i>Motor</i> : FGA (referenced)	FGA combined with (i) numeracy (serial subtractions, multiplications, divisions) and (ii) literacy (alt alphabet letters, days, and months). Cognitive task and FGA DT not fully reported	<i>General</i> : NR for cog component <i>Prioritisation</i> : No instruction on task prioritisation	- Score/30 - % response accuracy - FGA DTE = (DT - ST/ST)*100
Klotzbier & Schott (2017) [27]	TWT – walking while following (i) floor markings, (ii) numbers, and (iii) numbers + letters	<i>Motor</i> : Walk at fast, comf speed	Trail Walking Test (TWT) – walking while following (i) floor markings, (ii) sequential numbers, and (iii) sequential numbers + letters. Figure provided for navigation tasks. Pace NR	<i>General</i> : Used standard script (not provided). Instructed to: (i) follow a fixed pathway, (ii) step on targets with increasing sequential numbers (i.e., 1-2-3), and (iii) increasing sequential numbers and letters (i.e., 1-A-2-B). Instructed to move from one flag to the next one in ascending order as quickly, but as accurately as possible <i>Prioritisation</i> : No priority given to one domain	- Speed (m/s) - Errors (measured DTE but analysis not in scope)

3s three, 5s fives, alt alternating, cog cognitive, comf comfortable, CRR correct response rate, DT dual task, DTE dual task effect, FGA Functional Gait Assessment, m metres, NR not reported, s second, ST single task, TUG Timed Up and Go, TWT Trail Walking Test, WWT Walking While Talking test, # number, Δ change

General instructions

Only 14 of the 38 studies (37%) reported instructions for both the motor and cognitive components of the dual task; eight of these studies used the TUG. Of the remaining 24 studies (63%) that did not report instructions, 13 did not provide instructions for the cognitive component, and 11 did not report whether they gave standard instructions regarding how to complete the task.

Task prioritisation instructions

Almost half of the included studies (47%) did not report whether they gave instructions about task prioritisation; this included seven of the eight TUG studies (88%).

For studies that did report prioritisation instructions, they either reported: no explicit instructions about task prioritisation ($n = 11$), instructions to attend to both tasks or perform both as well as possible ($n = 6$) or to be as accurate as possible on the cognitive task ($n = 3$).

Practice trials

More than half of the 38 studies (57%) did not report giving a practice trial before recording the single and dual tasks.

Task order

Most studies reported the task order, either performing the ST first ($n = 10$), randomising ST and DT conditions ($n = 13$), performing ST then randomising DT order ($n = 5$), or another set sequence ($n = 1$). Nine studies did not clearly report the task order.

Number of trials recorded

Only 26 of the 38 studies (68%) reported the number of trials recorded, either 1 trial ($n = 11$ studies), 2 to 5 trials ($n = 12$), or 10 to 20 trials ($n = 3$).

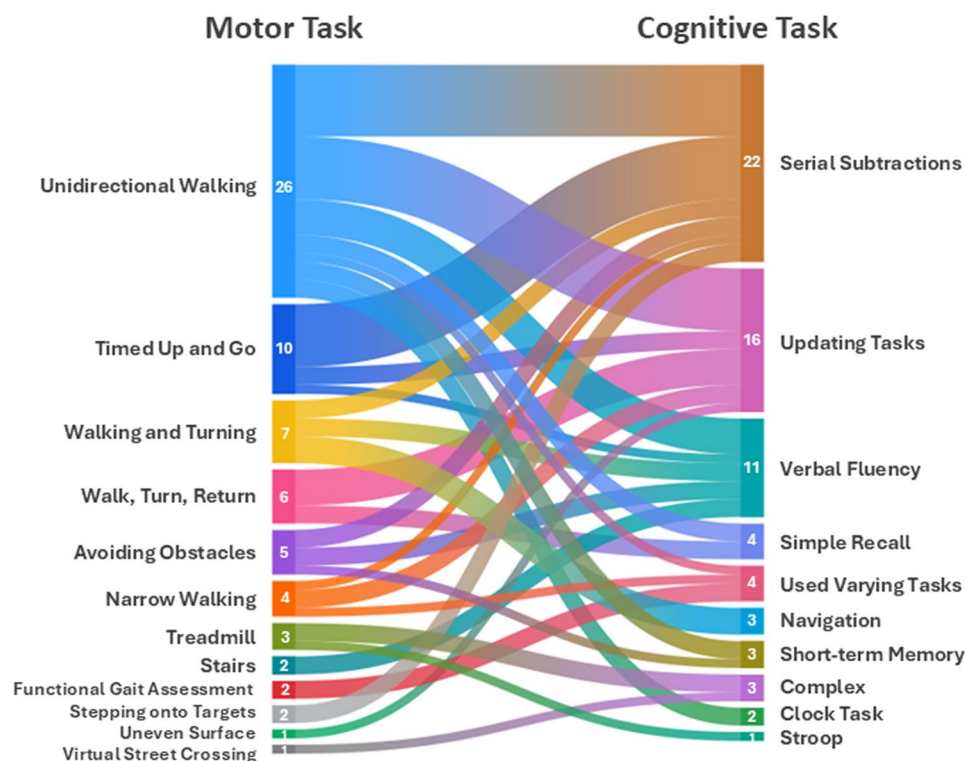


Fig. 2 Visual representation showing the range of motor and cognitive tasks that were combined in DT walking measurements. Line thickness represents the total number of times a specific motor–cognitive task pairing was used across all studies. The numbers in each column indicate how often each motor or cognitive task was used within a dual-task combination across all studies. Cognitive tasks were grouped to simplify visualisation. ‘Updating tasks’ required active maintenance, manipulation and updating of information (e.g., reciting alternate letters, counting backwards, reciting weekdays or months backwards, spelling words backwards) excluding serial subtraction which was separated because of its prominence. ‘Verbal fluency’ tasks involved producing a list of words based on a prompt (e.g., naming animals, words starting with certain letter). ‘Simple recall’ tasks required basic memory recall (e.g., reciting alphabet, counting forward in ones). ‘Used varying tasks’ includes studies that provided a range of cognitive tasks that could be used for a trial. ‘Navigation’ tasks required some form of real-world navigation using visual cues. ‘Short-term memory’ tasks required learning and holding information for a short period of time. ‘Complex’ tasks required coordination/integration of multiple domains (e.g., crossing a street while conversing, using head movements to align virtual objects)

Physical support

Only five studies (13%) reported the provision of close supervision during testing [13, 34, 39, 50, 52] but the other 33 studies did not describe the position of the assessor or potential for them to provide physical assistance if needed. Six studies reported rests were offered [32, 43, 56–58, 62].

Recording methods

For the non-instrumented studies, there was a lack of detail about raters and methods for manually rating outcomes. Only two studies [55, 59] discussed the number of raters for stopwatch recordings. Only two studies defined the start and end points for the stopwatch recordings [52, 57]. No studies reported who rated the cognitive responses.

For studies that included instrumented measures, 68% of studies provided details about where walking started in relation to the start of digital data recording. However, this information was missing for walkway recordings in

two studies, accelerometer recordings in four studies, and treadmill recordings in one study. One study referenced foot sensor data to the placement of obstacles to determine navigation errors, but it was not clear if this was a manual or digital process [33].

Data transfer and storage

A few studies described their data collection software (GAITRrite [31, 32, 35], MATLAB [40–42], or other wireless methods [29]). Only one study described storage [60].

DTE calculations and methods

Only 16 of the 38 studies measured DTE, but all studies reported their DTE calculation methods (Table 4).

Discussion

Despite the potential value of DT walking measures to capture valuable information regarding falls risk [8–10] and future cognitive decline [11], their utilisation within

Table 4 Dual task effect calculations used in the reviewed studies

DTE calculation method	Used by:	Origin of method
$\frac{\text{Difference between ST and DT}}{\text{ST}} \times 100$	Gabel et al. (2015) [35] Gillain et al. (2019a, [36] 2019b) [37] Hall et al. (2011) [15] Kim et al. (2017) [43] Lara et al. (2024) [45] Muhaidat et al. (2013) [57] Muhaidat et al. (2014) [58] Sulaiman et al. (2020) [62] Venema et al. (2019) [48]	Relative divided attention cost; Somberg & Salt-house (1982) [63]
DT – ST	Commandeur et al. (2018) [34] Kirby et al. (2021) [44] Shumway-Cook et al. (2000) [55] For cognitive DTE only: Muhaidat et al. (2013) [57] Muhaidat et al. (2014) [58]	Absolute divided attention cost; Somberg & Salt-house (1982) [63]
$\frac{\text{DT} - \text{ST}}{\text{mean of both}}$	Tomas-Carus et al. (2019) [56]	Dual task cost; Yamada et al. (2011) [64]
$\frac{\text{DT} - \text{ST}}{100}$	Borges et al. (2018) [13]	Mean of change scores; Borges et al. (2018) [13]
$\frac{\text{Motor DT} - \text{ST}}{\text{Motor ST}} + \frac{\text{Cognitive DT} - \text{ST}}{\text{Cognitive ST}}$	Liu et al. (2024) [61]	Δ Performance; Liu et al. (2024) [61]
ST plotted to draw curvilinear graph. Difference between DT value minus curve value at same speed (mm) was DTE	Nordin et al. (2010) [47]	Dual task cost; Nordin et al. (2010) [47]

clinical practice remains limited. Currently only one widely-used standardised test incorporates a cognitive-motor DT component—the Mini-BEST test, which includes the TUG test while counting backwards in threes [65]. This highlights the limited focus of previous research on the standardisation and development of DT measures specifically tailored for clinical practice—a significant gap in the field. To elucidate the challenges associated with replicating DT measures accurately and precisely, this review systematically scoped the reporting and standardisation practices within the existing literature. We found substantial variability in the administration of DT tests, corroborating previous reviews that have underscored the difficulties of synthesising data and formulating definitive clinical recommendations [7, 9, 10, 16]. Furthermore, inadequate standardisation of methods is likely to contribute to poor reliability and increased individual variability across testing sessions [4, 17]. This is particularly relevant to clinical practice where normal individual variation between treatment sessions may be confused for an improvement or decline in performance. By systematically charting the implementation of DT measures in research we have identified key areas for methodological refinement. These insights lay the groundwork for future development to enhance the robustness and clinical applicability of DT assessments, ultimately supporting their integration into routine

practice for the assessment and monitoring of age-related functional decline.

Procedures that introduce measurement variability

Measurement variability associated with the single task is compounded when two tasks are combined, resulting in poor to moderate reliability of DTE measures [4, 17]. This review utilised the COSMIN framework to extract potential sources of measurement variability [26]. Emphasis was placed on key procedural elements such as task instructions, prioritisation, and practice. Given that our inclusion criteria targeted studies likely to prioritise measurement reliability, it was notable, that fewer than half explicitly reported these factors.

Only a third of studies (37%) reported the general instructions given for carrying out both motor and cognitive components of the dual task, and only half of the studies (53%) reported instructions about task prioritisation. Research demonstrates that instructions about how to perform a task (e.g., accurately, as fast as possible) and use of an internal or external focus of attention (e.g., move your hand versus move the pen) alter a person’s cognitive strategies and motor performance [66, 67]. Similarly, the instructions accompanying memory and subtraction tasks—such as instructions about strategy [68], attention focus [69], and even gender relevance [70]—can alter cognitive performance. For older adults in particular, cognitive task performance can be impaired

by perceived stereotypes about their memory ability [71] and instructions that emphasise the memory component of a task [72]. Based on the poor reporting of task instructions seen in this review, it is not clear whether task instructions lacked standardisation, or whether authors failed to report this standardisation; however, either scenario limits the replication of DT tests. In the absence of standardised instructions, variability is introduced, which undermines the comparability of research findings across studies and the reliability of repeated measurements within individuals in clinical practice. Consequently, it becomes difficult to determine whether changes in DT outcomes reflect true differences in an individual's ability or simply variations in test conditions.

Most studies did not report conducting practice sessions. This is surprising given that rapid skill acquisition occurs when initially practicing a novel task [73]. This period of rapid acquisition is likely to take longer in older adults [74]. While the walking component of the DT may not be considered novel, factors such as environmental complexity and novel instructions regarding walking paths, turns, and pacing, can add a cognitive load initially and influence motor performance. Moreover, the cognitive component of a DT is often more unfamiliar to participants, potentially prolonging the duration of the initial learning phase and increasing the DTE. Incorporating practice trials can remove the variability associated with initial skill acquisition [75], potentially improving measurement reliability and the interpretation of DTE outcomes. Any practice trials should be standardised and clearly reported to ensure measurement procedures can be replicated in clinical practice.

Selecting the motor and cognitive task

Aside from error arising from a lack of standardisation, motor and cognitive tasks will inherently have some biological variability within individuals. Thus, for DT testing, it is important to choose motor and cognitive components that are reliable as single tasks, as any systematic error will be inflated when combining the two tasks in a DTE metric [4]. In addition, the choice of tasks should consider functional and clinical relevance and feasibility for use in clinical practice [20].

The commonly used motor tasks of unidirectional walking and TUG tests offer reliability as single tasks in older adult populations [76, 77], functional relevance, and feasibility. They may offer superior discriminatory power when used in a dual task scenario; in this regard, the TUG appears to hold particular value when combined with a mental tracking task (counting backwards in ones) for predicting falls [8]. More complex motor tasks seen in this review, such as those involving navigating around obstacles [45, 57–59] or following a trail [27] may not have established reliability as single tasks, yet offer

greater potential for increasing the motor challenge. This may be particularly relevant for more able-bodied older adults [78]. Instrumented walking assessments offer additional granularity, by capturing spatiotemporal parameters that may detect subtle, yet important changes in gait parameters [79, 80]. However, the walking distance must be considered. The instrumented studies in this review typically used a walking distance between 6 m and 25 m, which is generally sufficient for reliable measures of walking speed and step length [81], but may not be sufficient for measuring gait variability in single walking tasks [82, 83]. This has potential to contribute to the poor reliability of gait variability measures in DT assessments. While instrumented gait assessments currently present practical limitations, ongoing technological advancements are likely to improve their feasibility. Ordinal metrics such as step errors [27, 60], number of stops [56], or steps to completion [60] are more feasible as they can be collected manually, but their reliability warrants further investigation. Thus, there may be tension between these different priorities, but to ensure potential for clinical implementation, motor tasks with the lowest measurement error and most feasible procedures should be the focus of future research.

The choice of cognitive task is likely to be significant in ensuring the reliability of the DTE. The most common cognitive tasks used were serial subtractions (in threes, fives, or sevens), other updating or mental tracking tasks (e.g., reciting alternate letters or spelling words backwards), and verbal fluency tests (e.g., naming animals or words starting with a letter). Literature on the reliability of verbal fluency tests is relatively scant [84]. While serial subtraction measures are a component of several clinical cognition measures [85] and appear to have moderate reliability [86], there are persistent concerns about their validity [85] and the extent to which differences in mathematical ability can contaminate the measure [87]. Given the primary outcome in most of the studies reviewed was the change in motor performance under increased cognitive load, the ideal cognitive task should impose a relatively consistent cognitive load across all individuals. If the cognitive task's effect is inconsistent, then it may not be possible to distinguish between individuals' who have larger dual-task difficulties (i.e., where performance worsens due to the combination of two tasks) and individuals who are simply under greater cognitive load (i.e., where performance worsens due to the difficulty of the cognitive task alone). Various cognitive tasks are typically all treated as interchangeable ways of loading cognition in general, but they differ significantly in terms of the specific components of cognition that they target. Verbal fluency tests like naming animals or words starting with a letter are primarily designed to test a person's semantic, long-term memory systems (i.e., memory for factual

information that is not related to a specific event). Serial subtraction on the other hand, requires the coordination of attention, mathematical reasoning, and short-term memory. Given DT measures rely on the motor and cognitive tasks competing for shared resources, the choice of which cognitive systems to target could have important consequences for their reliability [7]. Previous work has shown that various cognitive tasks differ in their effect on gait [7] and, therefore, it will be important for future work to consider which cognitive systems to load when measuring DTE.

Standardising challenge

DT assessment is shaped by the multidimensional challenge arising from the interaction between motor and cognitive components. The concept of task challenge has been explored across various fields and several methods for setting task challenge have been highlighted [88]. Most DT studies in this and other reviews [9, 89, 90] standardised the challenge level of the cognitive task by asking all participants to perform the same task. A previous systematic review examining the complexity of secondary tasks during DT walking for falls prediction noted that DT studies appear to set challenge to the population of interest—for example, using easier tasks in studies of institutionalised populations [9]. Similarly, reviews in Parkinson's Disease [89] and neurological conditions [90] confirm the common use of non-individualised cognitive tasks (e.g., serial threes, days of week, counting tones, counting backward) in DT walking assessment. While this approach ensures uniformity, it does not account for individual differences in cognitive ability, such as those due to education level or relative strengths in numeracy and literacy.

An alternative approach is to standardise the challenge level of a set task to each person's ability—a concept known as relative or functional challenge [88]. This approach aims to achieve comparable levels of challenge of a set task, rather than identical tasks. Only one study in this review reported using this approach; Lara et al. (2024) [45] used the Digit Span Test to identify each participant's maximum recall length and applied this as the cognitive task while walking over obstacles. Personalising task difficulty to achieve comparable challenge levels—whether motor, cognitive, or combined—may enhance the sensitivity and interpretability of DT outcomes, ensuring observed changes reflect functional capacity [91, 92]. Importantly, individualised standardisation of challenge levels does not necessarily compromise measurement reliability, and has potential to remove outliers, although future research is needed to explore this. This approach is likely to be key to clinical implementation, where task difficulty relative to the individual influences the DT effect and its interpretation [20]. While this

concept is acknowledged in DT literature [91, 92], further evidence investigating integration of task design tailored to each participant's baseline ability would strengthen clinical implementation. Future research should also consider how procedures for setting task challenge account for factors beyond the motor and cognitive task components, such as environmental conditions, attention, fatigue, and motivation—many of which are difficult to control in real-world clinical settings and may limit the extent to which task challenge can be standardised.

Issues with interpretation become particularly evident if relying on DTE as a primary or sole outcome measure. DTE represents only the proportional change from baseline, without capturing absolute performance levels or the inherent difficulty of the tasks involved. As a result, similar DTE values may arise from markedly different performance profiles (e.g., uniformly poor versus uniformly high single- and dual-task performance), while differences in task nature and difficulty can produce contrasting dual-task effects. For example, Goh et al. (2021) [93] compared different motor-cognitive dual-task walking conditions in older adults. When completing single cognitive tasks, older adults produced very few correct responses for the serial sevens task (≈ 4 responses) but more for the animal naming task (≈ 13 responses). Under dual-task conditions, despite instructions to prioritise the cognitive task, cognitive performance improved for the animal naming task but declined for the serial sevens task, resulting in contrasting dual task effects. These differences likely reflect how single-task difficulty influences prioritisation and dual-task performance. Thus, interpreting DTE in isolation, without considering single task performance, is likely to be misleading. DTE should always be considered alongside raw single-task and dual-task scores to provide meaningful clinical insight, as recommended in previous literature [20].

Limitations

This scoping review has described a range of motor-cognitive DT walking measures investigated in cognitively-healthy older adults and critiqued the reporting of measurement procedures that may introduce measurement variability. The review used a systematic search that had been extensively tested, and pairs of blinded assessors for screening and data extraction, with additional cross-checking to increase the accuracy of findings. To maintain a feasible scope and focus on studies that described DT methodological procedures in detail, the review was restricted to studies that had examined validity or reliability. This decision excluded a broader body of literature that could have illustrated the diversity of motor-cognitive DT measures used in healthy older adults. While this is a limitation, studies with broader aims—such as those investigating population

characteristics or intervention effects, rather than DT measurement properties—are likely to provide less detail on measurement procedures, although some may report at a similar level to the included studies. Therefore, the gaps in reporting and standardisation identified here may be at least as prevalent—and possibly more pronounced—in the wider literature. Comparable gaps may also exist in studies involving younger or clinical populations, but these were beyond the scope of this review and would require dedicated reviews in those groups. While it was beyond the scope of this review to synthesise and critique the risk of bias of validity and reliability findings, the findings of each study are described in Supplementary File 2. It is also acknowledged that while the

population was deemed to be cognitively healthy, 15 of the 38 studies did not control for cognitive function with baseline cognitive testing. Instead, these studies relied on self-reported cognitive status or the absence of documented cognitive illness, which increases the likelihood that cognitively-impaired individuals were included. Future research should consider the expertise required to administer validated baseline cognitive assessments to ensure that cognitive function is appropriately accounted for. The review focused on the initial assessment of DT performance, but did not explore the potential for measures to be sensitive to change over time, nor considerations for retesting and adapting task challenge, all of which are essential to clinical implementation.

Table 5 Recommendations for measurement components that should be standardised and reported for dual task measurements (based on COSMIN framework)

Component	Report	Specifics
Equipment	Equipment required	Commercial recording equipment such as pressure-sensitive walkway, accelerometers, insoles, or video camera, with company details. Manual recording equipment such as pen, standardised recording sheet, clipboard. Equipment for setting up dual task environment such as cones, chair, or tape. Equipment for the cueing the cognitive task such as laptop, speakers, projector.
Preparatory actions	Equipment calibration	Calibration procedures prior to data collection, such as calibrating pressure-sensitive insoles using an air bladder.
	Equipment set up	Placement of equipment or floor markings, including distances. For example, video camera position, floor marker for start/end point, position of cones or chair.
	Preparation of the environment	Environmental details such as room size, lighting, noise levels.
	Preparation of the patient by the professional	Any equipment placed on the person's body such as wearable sensors, safety belt, or harness, and the method for applying this.
	Preparation undertaken by the patient	Footwear, clothing requirements, any preparatory activities (e.g., resting for 15 min).
Collection of raw data to ensure consistency	Required expertise or training for professionals to prepare, administer, store or assign scores	Professional background, training given (duration and method), and criteria to determine training is complete.
	General instructions to participant #	Standardised instructions given. Instructions describe the motor and cognitive task requirements, when to start (e.g., when I say "Go") and stop, as well as pace and safety (e.g., walk as quickly and safely as possible).
	Instructions to participant about task prioritisation #	Standardised instructions given regarding which task to prioritise and how it should be prioritised (e.g., for accuracy or speed), or whether no instructions were given about task prioritisation.
	Practice trials #	Number of practice trials and what they entailed (e.g., distance, duration). Any criteria to determine task is familiar.
	How tasks were performed	Sufficient detail to reproduce as single tasks and DT
	Method for collecting raw data	Start and finish point for recording, recording methods (manual or digital), details of manual raters (i.e., who, how many), and raw data/metrics collected. Include details for recording both motor and cognitive performance.
	Number of recorded trials #	Number/ duration of repetitions for motor and cognitive tests as ST and for DT trials
Data processing and storage	Details of any standardised protocols in cited literature #	Citation for references/ published protocols
	Method for handling data (transferring, saving)	Software, automated recording or calculating tools
Assignment of scores	Method for translating raw data into scores or metrics	Methods for converting raw data into metrics or scores for ST and DT performance (e.g., errors per second, walking speed). Data processing methods employed (e.g., average of three trials).
	Dual task effect calculations (if applicable) #	Calculation method for DTE (if applicable)

Categories from COSMIN framework Part A which identifies sources of measurement variability [26].# Additional components specified for dual task assessment

Recommendations for reporting dual task methodological procedures

While the value of DT assessment as a clinical tool is well recognised, current approaches to its administration, calculation or interpretation are lacking. Had these methodological and interpretable challenges been fully addressed, DT assessments may be more widely and routinely integrated into clinical practice. The gaps in reporting identified in this review must be addressed in future research. To facilitate this, Table 5 provides recommendations for the standardisation and reporting of DT measurements. It is acknowledged that journal word limits may restrict comprehensive reporting of methodological procedures; in such cases, authors should consider using supplementary materials or protocol registries. Further investigations need to systematically control for, and examine, the influence of various DT elements such as instructions, practice trials, and scoring methods. This work on standardisation is a prerequisite to ensuring DT measures can detect real changes in performance, rather than simply detecting measurement error. This will pave the way for determining which DT measures are the most sensitive to change, which is essential for the integration of DT assessments as robust tools within research and clinical practice.

Conclusion

Dual task walking assessments offer unique insights into functional capacity and may be a useful indicator of healthy aging and age-related decline. This scoping review examined the range of motor-cognitive DT walking assessments used in healthy older adults and systematically evaluated their reporting and standardisation. There was substantial variability in the administration of DT assessments, and no studies provided sufficient details to enable accurate replication. Among the sources of measurement variability, of significant concern was the lack of reporting of task instructions, for both the overall task and for task prioritisation, and practice trials were not used in over half of the studies. Other areas with inadequate reporting included the expertise and training of the evaluator, patient preparation (e.g., footwear), and supervision or support provided during testing.

This review has highlighted a lack of reporting, and standardisation practices that threaten the accurate and precise replication of DT measures in clinical practice. The review offers recommendations for standardising and reporting DT measurement procedures, including the provision of standardised instructions for the task and task prioritisation, practice trials, specified assessor training, and consistent preparation of patients and the environment. Rigorous reporting of these elements is a critical stepping stone toward refining DT assessments, strengthening their reliability and replicability, and optimising their potential for clinical translation to evaluate age-related functional decline.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12877-026-07214-2>.

Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Authors' contributions

SO, SC, DH, and DT conceptualised the study. SO, AS, SC, and RM developed the methodology. SO, AS, and SC screened the articles. SO, SC, RM, and NS extracted data and SO, SC, and NS curated and verified the data. DH and SO created the data visualisation. SO, AS and RM prepared the draft manuscript. All authors contributed to results interpretation and read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Ethical approval not required for secondary analysis. Primary studies included in the review gained participant consent.

Competing interests

The authors declare no competing interests.

Author details

¹Faculty of Health and Environmental Sciences, Auckland University of Technology, Auckland, New Zealand

²New Zealand Dizziness & Balance Centre, Auckland, New Zealand

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