***Journal of Aging and Physical Activity*, 2023, 31, 823-832**
https://doi.org/10.1123/japa.2022-0304

Human Kinetics
ORIGINAL RESEARCH

Dual-Task Interference of Gait Parameters During Different Conditions of the Timed Up-and-Go Test Performed by Community-Dwelling Older Adults

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The Timed Up-and-Go (TUG) test has been combined with different verbal/cognitive tasks (i.e., TUG dual task [TUGdt]) as a form of motor-cognitive testing. However, it is still unclear how different TUGdt conditions affect gait among older adults. Thirty community-dwelling older adults, with mean age of 73 years, participated in the study. Data were collected using marker-free video recordings. Gait parameters were extracted using a semiautomatic deep learning system. Comparisons of execution time and gait parameter outcomes were made under TUG and three types of TUGdt test conditions: TUGdt-naming animals, TUGdt-months backwards, and TUGdt-serial 7s. Statistical analyses were based on mean values of the gait parameters for each participant and TUG condition, including TUGdt gait cost, that is, the relative difference between TUGdt and TUG. All the investigated TUGdt conditions resulted in varying degrees of gait parameter changes. Under TUGdt conditions, participants took shorter and slower steps, with TUGdt-serial 7s causing the largest interference.

***Keywords**:* mobility, executive function, video

Based on the notion that motor control and cognition involve overlapping brain networks (Pashler, 1994), interest in research into the area of gait and cognitive functioning has increased. A growing number of studies focusing on cognitive–gait interference have focused on different test procedures that combine motor performance with a simultaneous cognitive/verbal task, defined as dual-task (dt) testing (Montero-Odasso et al., 2019). The underlying mechanisms that affect dt gait performance have been referred to as a "brain stress test" that provides an explanation for such dt interference (Montero-Odasso et al., 2017).

The most common dt tests intended for motor-cognitive interference examination involve straight-line walking while performing a cognitive task that is usually verbal, with gait speed as the most frequently used dt cost outcome (Al-Yahya et al., 2011; Goh et al., 2021; Smith, Cusack, et al., 2017). The dt cost, that is, the relative difference between performances during single and dt conditions (Montero-Odasso et al., 2019), has been suggested as a promising outcome that is associated with dementia progression (Cullen et al., 2019; Montero-Odasso et al., 2017). It has also been shown that specific gait characteristics derived from dt tests in a preclinical stage and in mild cognitive impairment are associated with the risk of developing specific dementia types (De Cock et al., 2019).

The verbal component of dt testing can, for example, involve an arithmetic task (continuous subtractions), verbal fluency task (reciting animals or names or phonemic fluency), or reciting the alphabet (Al-Yahya et al., 2011; Beauchet et al., 2005; Goh et al., 2021; Smith, Cusack, et al., 2017). Even though there is no consensus regarding which cognitive task to combine with walking, they are not interchangeable (Montero-Odasso et al., 2020). It is, however, agreed that the level of difficulty should be close to the threshold of the target population's capacity to provide an adequate attentional load affecting the overall test performance. Despite the variation of test procedures, previous studies have shown that diverse gait parameters are affected by adding a cognitive task to walking (Al-Yahya et al., 2011; Smith, Cusack, et al., 2017).

The dt interference of gait also appears to be age related, with a more pronounced decrease in performance and a higher dt cost seen in older adults than in middle-aged and younger adults (Brustio et al., 2017). One systematic review and meta-analysis (Al-Yahya et al., 2011) found that cognitive tasks involving internal interference factors (such as mental tracking) appear to cause more gait disturbances than those involving external factors (such as reaction time). The downward effect of dt on gait speed in this study was more prominent among older adults. In a comparison (Goh et al., 2021) between older and younger adults performing straight-line walking under four dt conditions of varying degrees of difficulty—mental tracking (counting backwards), recalling list (remembering a short item list), reaction time (responding to an audio stimulus), and verbal fluency (naming fruits/animals)—the dt gait speed cost for both groups across most conditions was found to increase (i.e., gait slowed) as the task difficulty increased. Although dt gait speed cost has been suggested as the most relevant outcome parameter in dt

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testing in older adults (Montero-Odasso et al., 2019), there is no consensus regarding the optimal outcome parameter.

In addition, a more complex mobility task than straight-line walking has been used in recent dt studies (Cedervall et al., 2020; Nielsen, Simonsen, Siersma, Hasselbalch, & Hoegh, 2018), namely, the Timed Up-and-Go (TUG) test (Podsiadlo & Richardson, 1991). TUG has been tested with satisfactory results for the assessment of gait and mobility, for which it does not suffer from any ceiling or floor effects in healthy older adults (Herman et al., 2011), and has shown to possess good reliability for people with and without disabilities across a life span (Christopher et al., 2021). The TUG involves both walking and transitions (rising up from sitting, walking, turning, and sitting down), and, hence, depends to a greater degree on executive functions when compared to straight-line walking (Herman et al., 2011). However, the association between TUG and cognitive ability has been viewed as limited in healthy older adults and assumed to possess more significant meaning for people with impaired cognition (Herman et al., 2011). Thus, the TUG has been shown to be an appropriate tool for clinical assessment of functional mobility in healthy older adults and to be related to executive function (Herman et al., 2011), since the complexity of the TUG subtasks (Bayot et al., 2018) challenges executive functions more than gait alone (Donoghue et al., 2012). Executive dysfunction may be indicated by a prolonged TUG time score because TUG involves fluid transitions between the subtasks (Mirelman et al., 2014), something that is not embodied in straight-line gait speed. TUG is also related to spatial orientation (Costa et al., 2020). Therefore, it can be assumed to cause a more extensive dt interference than straight-line walking when combined with the same cognitive/verbal task.

In previous dt studies involving TUG, time scores and the qualitative evaluation of gait performance have been investigated (Borges Sde et al., 2015; Cedervall et al., 2020; Nielsen et al., 2018). How gait parameters are affected has been less extensively explored, even though a limited number of studies have shown that TUGdt is associated with a reduced cadence (steps/min), shorter stride length, longer stride time, and slower stride velocity compared to single-task (st) conditions (Coulthard et al., 2015; Smith, Walsh, et al., 2017). Despite these findings, it is still unclear how different TUGdt conditions affect gait parameters among older adults.

The aim of this study therefore was to investigate the interference of gait during older adults' performance of three distinct types of TUGdt test conditions and to compare the outcomes between them, as well as in relation to TUG as a st test (hereafter named TUGst). For this purpose, we utilized a novel approach for gait parameter analysis of video-recorded TUGst and TUGdt tests (Åberg et al., 2021).

Materials and Methods

Context and Participants

The study was conducted at the Biomechanics and Motor Control Laboratory, at the Swedish School of Sport and Health Sciences, Stockholm. Thirty persons without any diagnosed cognitive impairment were recruited among participants in a health study in which regular physical exercise was included. Inclusion criteria are as follows: no self-reported cognitive impairment diagnosis or self-reported severe mobility limitations, fluent Swedish speaker, and age 60 years or older (see Table 1). Exclusion criteria are as follows: need of an interpreter, inability to rise from a sitting position with or without use of arms to push up, inability to walk 3 m back and forth, or indoor use of a walker. The Swedish Ethical Review Authority approved the study (dnr. 2019-03282). The

Table 1 Characteristics of Study Participants Presented as a Median (Min–Max), Except University Educated Presented as Quantity

	Men	Women	Total
N	**14**	**16**	**30**
Age (years)	77 (69 to 83)	69.5 (60 to 85)	73 (60 to 85)
University educated (*n*)	8	12	20
Body length (cm)	180.3 (171 to 185.5)	165.8 (151 to 174.5)	171.3 (151 to 185.5)
Walking speed (m/s)	1.3 (1 to 1.7)	1.2 (0.8 to 1.9)	1.3 (0.8 to 1.9)
Handgrip (kg)	38 (24 to 51)	26 (17 to 34)	29 (17 to 51)
MMSE score	29 (24 to 30)	29 (25 to 30)	29 (24 to 30)
TUGst time (s)	9.3 (7.4 to 13.8)	9.7 (7.7 to 13.4)	9.6 (7.4 to 13.8)
TUGdt naming animals time (s)	11.0 (7.6 to 22.3)	11.0 (8.4 to 15.5)	11.0 (7.6 to 22.3)
TUGdt number of named animals	7 (5 to 10)	8 (5 to 11)	7 (5 to 11)
TUGdt naming animals costs (%)	10.2 (–5.5 to 92.1)	10.0 (–2.2 to 43.7)	10.0 (–5.5 to 92.1)
TUGdt number of named animals per 10 s	7.1 (3.1 to 10.4)	6.9 (3.7 to 11.2)	6.9 (3.1 to 11.2)
TUGdt reciting months backwards time (s)	11.0 (7.4 to 32.7)	11.9 (8.4 to 20.8)	11.6 (7.4 to 32.7)
TUGdt number of recited months	8.5 (4 to 11)	9 (5 to 12)	9 (4 to 12)
TUGdt reciting months backwards costs (%)	13.2 (–6.8 to 182.1)	19.6 (–2.5 to 68.5)	15.6 (–6.8 to 182.1)
TUGdt number of recited months per 10 s	7.9 (2.8 to 12.0)	7.8 (4.3 to 11.1)	7.8 (2.8 to 12.0)
TUGdt serial 7s time (s)	12.2 (8.2 to 43.0)	13.5 (9.2 to 34.3)	12.6 (8.2 to 43.0)
TUGdt number of counted serial 7s	3.5 (1 to 6)	3 (0 to 8)	3 (0 to 8)
TUGdt serial 7s costs (%)	23.4 (–0.69 to 270.9)	29.1 (–6.2 to 318.2)	26.5 (–6.2 to 318.2)
TUGdt number of counted serial 7s per 10 s	2.4 (0.47 to 5.8)	2.2 (0 to 3.1)	2.2 (0 to 5.8)

Note. MMSE = Mini-Mental State Examination; TUGst = Timed Up-and-Go single task; TUGdt = Timed Up-and-Go dual task.

Helsinki Ethical Declaration was applied, and informed consent was obtained from all participants prior to study commencement.

Data Collection

All data collection was carried out by two physiotherapists experienced in the geriatric field; one led all the standard motor and cognitive tests and another all the TUG tests, as described below. For descriptive purposes, three standard tests of motor and cognitive functioning were used and performed in the following order: handgrip strength measured by a dynamometer (Bohannon, 2017), 10-m standing start usual walking speed (Peters et al., 2013), and Mini-Mental State Examination (Folstein et al., 1975). The experiments also used a standard TUG test (Podsiadlo & Richardson, 1991). This involves one movement sequence: starting from a sitting position in an armchair, standing up, walking 3 m, turning around, walking back to the armchair, and sitting down again (Figure 1). The TUGdt test conditions investigated were as follows: TUGdt-naming animals (TUGdt-NA), TUGdt-months backwards (TUGdt-MB; Cedervall et al., 2020), and TUGdt-serial 7s (Manning, 1982; TUGdt-S7). We hypothesized that these tasks would entail a progressive increase in motor-cognitive demands and a corresponding increase in interference compared to TUGst, with TUGdt-NA showing the least interference, TUGdt-MB more interference, and TUGdt-S7 the most interference. To the best of our knowledge, this is one of the very first studies examining the interference of gait parameters during TUG tests in different dt conditions (hereafter named TUGdt gait interference) and participant experiences of the test procedures.

The TUG tests in this study were executed under four different conditions. TUG as a st test (TUGst) was conducted first. Thereafter, TUG was combined with a cognitive/verbal task constituting three different TUGdt conditions: TUGdt-NA, TUGdt-MB, and TUGdt-S7. The cognitive components of the TUGdt test conditions were carefully chosen: naming animals and reciting months backwards were based on our clinical experience and previous research that predominantly included individuals with different degrees of cognitive impairment (Åberg et al., 2021; Cedervall et al., 2014, 2020). The serial 7s, a measure of complex attention involving counting down from 100 by seven (Manning, 1982), was chosen as a more demanding task that would be more prone to provoking gait changes in the test performance of the current sample. This assumption was based on results from a previous study, which showed that in persons with Parkinson's disease and healthy older adults, the serial 7s test was the most effective TUGdt condition to affect walking speed (Zirek et al., 2018). This implies that the used TUGdt tests can be described as tests with multiple components combining two single-goal tasks, of which the verbal components possess different levels of cognitive complexity and challenge (McIsaac et al., 2015).

In order to represent increasing difficulty, these tests were performed in the order as mentioned above. The cognitive components of both TUGdt-NA and TUGdt-MB target semantic memory and executive function (Henry et al., 2004; Meagher et al., 2015; Vaughan et al., 2018). The component of TUGdt-S7 depends more on working memory and attention. The participants were instructed by an experienced physiotherapist to complete all TUG tests at their own speed and to complete the mobility sequence of the TUGdt tests even if they could not complete the verbal task. As a final step of the data collection, a pen-and-paper questionnaire was administrated to investigate the participants' experiences of each of the three investigated TUGdt procedures. The questionnaire included the instruction to mark what matched the participant's opinion best on a 0- to 10-point Likert scale regarding the statement *I think the … test was*: stressful, difficult, interesting, or amusing, with one scale for each question (see Supplementary Material [available online]).

All TUG tests were instructed to be performed at a self-selected comfortable pace. Standardized instructions were given to the participants before each test. TUGst was performed according to the original test procedures (Podsiadlo & Richardson, 1991): starting from a sitting position in an armchair (with sitting height of 45 cm), standing up (with or without pushing up by the use of arms), walking 3 m, turning around, walking back to the chair, and sitting down again. The test leader timed the performance with a stopwatch from the moment the test person's back left the backrest until their posterior touched the seat of the chair again. For TUGdt-NA, the participants were instructed to name different animals while completing the movement sequence. For TUGdt-MB, they were asked to recite months in reverse order, starting from December. For TUGdt-S7, they were asked to count down from 100 by seven. The number of correct values from the serial 93-86-79-72-65-58-51-44-37-30-23-16-9-2 was counted as a result of the serial 7s. The result was defined as the number of correct values before the first error occurred or when the person stopped counting. The test leader was not allowed to give additional instructions for encouragement or cueing during the tests.

Functional tests
10-m walking speed
Handgrip strength
Mini-Mental State Examination

Video-recorded Timed Up-and-Go (TUG) single- and dual-task (dt) tests
TUG single task
TUGdt: Naming animals, months backwards, and serial 7s, respectively

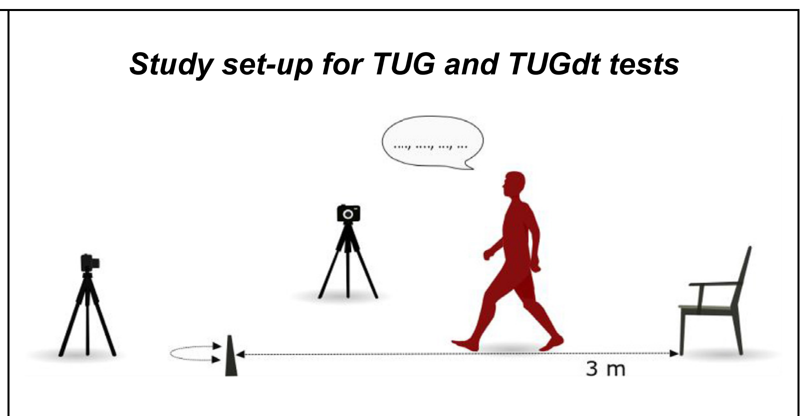

Figure 1 — Overview of data collection tests and study setup. (Image derived from H.B. Åhman [Åhman, 2021]).

The TUG tests were recorded by two synchronous video cameras (Sony NEX-5T) on tripods. One camera placed 2 m in front of the line where the participant turned (front view) and the other 4 m to the side of the line along which the participant walked (side view). The cameras each had 81° of horizontal field of view. Digital high-definition video (1,080p) was recorded at a frequency of 25 Hz. Six reference marks were placed at known locations on the floor for calibration of the video cameras. The calibration involved determining the homography that maps pixel coordinates in the video images to world coordinates on the floor, with the *x*-direction defined as the horizontal direction from the chair to the 3-m line, and the *y*-direction perpendicular and pointing to the left as seen from the chair.

Data Processing

The gait parameters quantified were as follows: step duration (SD), double-stance duration (DSD), single-stance duration (SSD), step length (SL), and step width (SW). These were extracted from marker-free video recordings using an innovative semiautomatic procedure utilizing the deep learning system OpenPose (Cao et al., 2021).

One rater (co-author K. Halvorsen) carried out the data processing procedure for extraction of gait parameters from the video recordings. This process has been described in more detail elsewhere, including evaluation of validity, using an optical motion capture system as gold standard, as well as for inter- and intrarater reliability, with satisfactory results, by (Åberg et al., 2021, 2022).

The data preparation procedure is semiautomatic; it makes use of approximate anatomical landmarks identified by the deep learning system OpenPose (Cao et al., 2021). The gait events *heel-strike* and *toe-off* are identified using the following definitions. The image frame (and hence time stamp) corresponding to the heel-strike event is defined as the first frame after the swing phase, where the heel of the shoe is in contact with the floor and the foot is plantar flexed in comparison to the previous frame (Figure 2). The image frame corresponding to the toe-off event is defined as the last frame before the swing phase in which the shoe is in contact with the floor and there is a visible deformation of the toe part of the shoe. To calculate SL and SW, points are manually marked on the heel-strike images. In the side-view image, the most posterior point of the contact between heel and floor is marked, and in the frontal view, the mark is placed at the contact with the floor with the most lateral point of the heel. For SL, only steps away from the camera are considered (from the 3-m line toward the chair), since the heel point is not visible when the person is walking toward the camera.

For each participant, all steps were analyzed starting from the second heel strike after rising from the chair and excluding all steps on the far side of the 3-m line. Steps close to the chair on the return that showed clear signs of preparation to turn and sit down

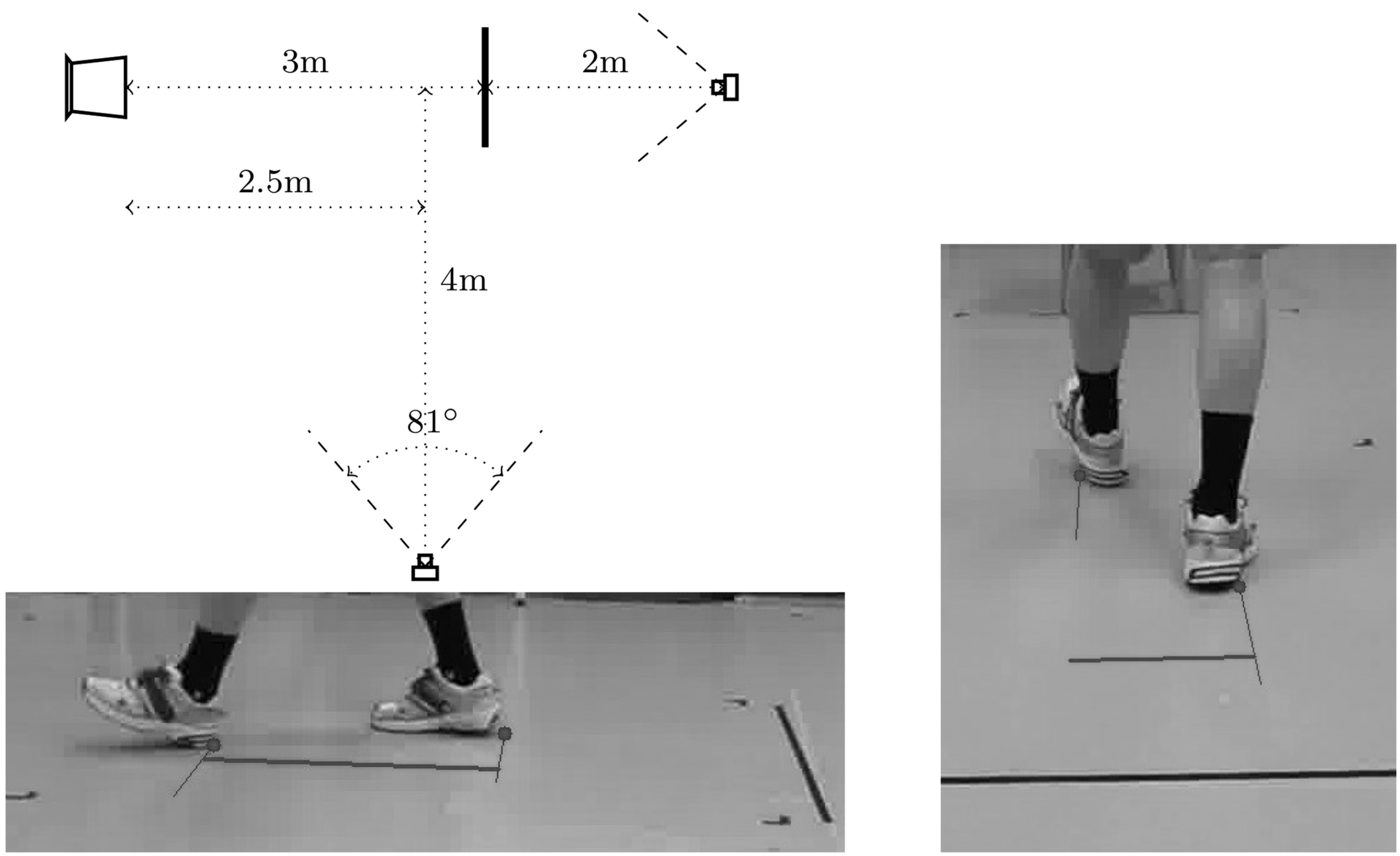

Figure 2 — Experimental setup shown together with an example of step length and step width measurements extracted from side-view (left) and frontal-view (right) videos.

were also excluded (Cao et al., 2019; Jolliffe, 2002). This resulted in a mean of 6.0 processed steps per participant and TUG condition with a range of two to 14 steps. Based on the identified events and heel point positions, the following gait parameters were determined: SL was defined as the distance between posterior points on heels in the direction from the chair to the 3-m line marking (horizontal *x*-direction; Figure 2), and SW was defined as the distance between lateral heel points in the horizontal *y*-direction. SD, SSD, and DSD were calculated from the times(s) of the identified gait events.

Statistical Methods

For each participant and TUG condition, the mean value of all recorded steps was calculated for each gait parameter. These mean values were used in the statistical description and analysis as original values for all conditions and as TUGdt gait interference values. The relative difference between TUGdt and TUGst was calculated as $100 \times$(TUGdt gait parameter value-TUGst gait parameter value)/TUGst gait parameter value for TUGdt-NA, TUGdt-MB, and TUGdt-S7, respectively. Furthermore, the mean values before and after the TUGdt turning point were calculated for each participant and TUG condition. Median values of the Likert scale scores were used for quantification of participant experiences.

Data were presented by condition with mean, *SD*, and minimum and maximum values, or median and minimum and maximum values. The normality assumption was examined using the Shapiro–Wilk test, where values of the test statistic $w > 0.95$ indicated normality on the original scale or logarithmic scale. Times required to complete TUG tests (the three TUGdt tests and TUGst) were compared using Wilcoxon's matched-pair signed-rank test. Assuming normal distribution, a repeated-measures analysis of variance model was performed, and when normal distribution could not be assumed, the Friedman test was performed to compare the four conditions for original gait parameters, for comparison of the three TUGdt gait interference parameters, and for comparison of original parameters before and after the TUGdt turning point separately for the four conditions. Median values of the Likert scale scores were compared between the three TUGdt conditions with the Friedman test. Bonferroni correction of *p* values was used to adjust for multiple testing. A comparison was considered statistically significant when $p < .05/6$ (six pairwise comparisons) for time required to complete TUG tests and original gait parameters and when $p < .05/3$ (three pairwise comparisons) for TUGdt gait interference parameters and for Likert scale scores.

Statistical descriptions and analyses were performed using Statistica (version 13.4) and SAS (version 9.4).

Results

An overview of the 30 community-dwelling older adults (mean age was 73 years), participants of whom 16 were women, is displayed in Table 1, including descriptive statistics of the results from the functional, TUGst, and TUGdt tests. No one among them had any cognitive-related diagnoses, but 11 reported memory complaints when responding to a dichotomous question. They were all community dwelling. Their TUGst time ranged widely from 7.4 s to 13.8 s, with one person just over the cutoff value of 13.5 s, indicating poor mobility (Herman et al., 2011). Their self-selected 10-m walking speed was normal according to age- and gender-related reference values (Bohannon & Williams Andrews, 2011) with a median of 1.3 m/s. Twenty-eight of the participants had a normal handgrip strength (median = 29.3 kg), thus exceeding the cutoff values for identifying mobility limitations and factors associated with muscle weakness in community-dwelling older adults (Vasconcelos et al., 2016). Only two, one man and one woman, had handgrip strength values that fell marginally under the cutoff values. (Souza Vasconcelos et al., 2016). The Mini-Mental State Examination scores of the participants ranged from 24 to 30. If a cutoff Mini-Mental State Examination is placed at 26, which has recently been suggested as reasonable for unimpaired cognition among older adults up to the age of 93 years (Kvitting et al., 2019), this might imply some minor cognitive difficulties in a small number of participants. Despite some functional limitations, as indicated above, these descriptive results show that our study population is mainly physically and cognitively normal.

In general, the participants' gait pattern was disturbed by the performance of TUGdt compared to TUGst: It took significantly longer to complete the TUGdt task tests than the TUGst ($p < .001$; Table 1). Moreover, TUGdt-S7 took significantly longer than both TUGdt-NA and TUGdt-MB ($p < .01$), with no significant difference between the latter two.

The dt interference with the examined gait parameters showed significant differences across different comparisons (Table 2). Comparisons of gait parameters under TUGdt conditions compared to TUGst showed significant ($p < .0083$) differences in all temporal gait parameters, with increased dt durations at levels of differences ranging from 2 to 10 hundredths of a second, with the largest differences in SD.

Analyses of the spatial parameters showed shorter SLs in comparisons between TUGst against both TUGdt-MB and TUGdt-S7, as well as between TUGdt-NA and TUGdt-S7, with differences ranging from 4 to 6 cm. Regarding SW, no differences were shown.

Analyses of the TUGdt gait interference (Table 3) showed significantly ($p < .0167$) more interference in SD for TUGdt-S7

Table 2 Gait Parameters for the TUG Test Conditions

TUG condition	Step duration (s) Median (min, max)	Double-stance duration (s) Median (min, max)	Single-stance duration (s) Median (min, max)	Step length (m) Mean (std) (min, max)	Step width (m) Mean (std) (min, max)
Single task	0.57 (0.50, 0.68)[a]	0.12 (0.05, 0.20)[a]	0.44 (0.40, 0.54)[a]	0.61 (0.09) (0.41, 0.82)[a]	0.18 (0.04) (0.09, 0.26)[a]
Naming animals	0.65 (0.49, 1.15)[b]	0.14 (0.06, 0.40)[b,c]	0.50 (0.41, 0.75)[b]	0.59 (0.10) (0.36, 0.87)[a,b]	0.18 (0.04) (0.11, 0.26)[a]
Months backwards	0.66 (0.49, 1.30)[b]	0.15 (0.04, 0.44)[c,d]	0.51 (0.45, 0.86)[b]	0.57 (0.10) (0.32, 0.81)[b,c]	0.19 (0.04) (0.09, 0.29)[a]
Serial 7s	0.67 (0.52, 1.94)[c]	0.17 (0.09, 0.51)[d]	0.50 (0.41, 1.49)[b]	0.55 (0.10) (0.32, 0.74)[c]	0.18 (0.04) (0.11, 0.27)[a]

Note. TUG = Timed Up-and-Go. Conditions with different letters are significantly different with Bonferroni correction ($p < .0083$). For example, for double-stance duration, single task is significantly different from all other conditions, naming animals is further significantly different from serial 7s, and months backwards is not significantly different from naming animals or from serial 7s.

Table 3 Dual-Task Gait Interference (%) for Gait Parameters by TUGdt Test Condition

TUGdt condition	Step duration Median (min, max)	Double-stance duration Median (min, max)	Single-stance duration Median (min, max)	Step length Mean (std) (min, max)	Step width Median (min, max)
Naming animals	13.5 (–10.4, 70.8)[a]	14.7 (–50.0, 191.7)[a]	12.2 (–1.8, 40.0)[a]	–3.2 (6.2) (–15.2, 7.6)[a]	–2.5 (–28.6, 98.8)[a]
Months backwards	16.3 (–10.4, 92.8)[a]	33.3 (–66.7, 253.3)[a]	12.5 (–0.0, 59.2)[a]	–6.8 (7.9) (–22.7, 7.8)[b]	–1.2 (–38.9, 47.8)[a]
Serial 7s	21.8 (–4.9, 238.4)[b]	50.0 (–11.1, 264.3)[b]	15.4 (–3.1, 230.0)[a]	–9.0 (9.7) (–31.5, 10.5)[b]	–5.6 (–31.4, 48.6)[a]

Note. TUGdt = Timed Up-and-Go dual task. Conditions with different letters are significantly different with Bonferroni correction ($p < .0167$). For example, for double-stance duration, naming animals, and months backwards are significantly different from serial 7s, but naming animals and months backwards are not significantly different from each other.

than both TUGdt-MB and TUGdt-NA (ranging from 13.5% to 21.8%), and in DSD for TUGdt-S7 compared to both TUGdt-MB and TUGdt-NA (ranging from 14.7% to 50.0%). Moreover, greater negative TUGdt gait interference for SL was shown for both TUGdt-MB (–6.8%) and TUGdt-S7 (–9.0%) than for TUGdt-NA (–3.2%). No differences concerning TUGdt gait interference between any of the test conditions were shown in SSD or SW.

The comparisons of gait parameters before and after the TUG turning point are shown in Table 4, with results showing significant differences ($p < .05$) after the turn for TUGst, with increased SD and SW. SD and DSD were increased and SL was decreased for TUGdt-NA. For TUGdt-MB SD, DSD and SSD were increased after the turning point. No before/after difference was shown for TUGdt-S7 in any of the gait parameters. For TUGdt-MB, SSD was shorter, lower after the turning point.

The participants reported that they found the TUGdt-S7 test procedure more stressful (Median = 5) and difficult (Median = 7), compared to TUGdt-NA and TUGdt-MB (Median 2–3; $p < .001$; Figure 3). In fact, one participant refused to carry out TUGdt-S7 because of their previous negative experiences of mathematics at school. Nevertheless, all of the TUGdt test procedures were judged to be interesting and amusing (Median 6–8), with a lower estimation for TUGdt-MB/interesting (Median = 6) than TUGdt-S7/interesting (Median = 8; $p = .02$).

Discussion

The results show significant gait pattern changes under dt conditions, with participants taking shorter and slower steps. There was a demonstrable increase across all of the temporal gait parameters in SD, DSD, and SSD, together with significant interference for the spatial parameter SL. On the other hand, no significant TUGdt gait interference was shown in SW for any of the test conditions. This could be a consequence of relatively large individual variations and few steps analyzed for SW. Only the steps in the direction away from the camera were analyzed, for which the heel was clearly visible in the image. We observed a slower execution of all of the investigated TUGdt conditions (11.0–12.2 s) compared to TUGst (9.3 s), with TUGdt-S7 being the slowest and, thus, apparently the most challenging, TUG condition. Conversely, no significant time difference between TUGdt-NA and TUGdt-MB was shown. These results are in agreement with previous research claiming that dual tasking often entails a reduced gait speed in line with increased demands on executive functioning and attention (Yogev-Seligmann et al., 2008).

The dt gait interference identified in the current study may be regarded as a sign of “brain stress” (Montero-Odasso et al., 2017), caused by an increase in motor-cognitive demands. This might be worth investigating further, since specific gait characteristics derived from dt tests in a preclinical stage are associated with the risk of developing specific dementia types (De Cock et al., 2019). Moreover, according to a systematic review of brain activity during dt gait and balance, it has been shown that first, the interference or cost of performing dt gait and balance is greater in older adults and in people with age-related neurodegenerative conditions, and, second, that reduced ability to allocate sufficient attentional resources may result in increased risk of falls and loss of independence in older adults with or without age-related neurodegenerative conditions (Kahya et al., 2019). However, the clinically relevant levels and cutoff values of dt gait interference of specific dt test procedures still remain to be investigated and identified.

A greater dt gait interference by TUGdt-S7 compared to TUGdt-NA and TUGdt-MB was shown in total execution time as well as in SD. TUGdt-S7 showed a shorter SL than TUGdt-NA. However, no such differences were shown between TUGdt-NA and TUGdt-MB. In contrast, a study involving a comparison between two types of TUGdt (TUG combined with counting backward from 100 and TUG-NA), each with the instruction to perform the task as quickly as possible, showed distinctly opposite results, with the task resulting in poorer motor task during TUG performance than the counting task. This study also showed that lower educational attainment was significantly associated with poorer dt performance (Tomas-Carus et al., 2020). Differences in the formulation of task performance instructions may provide a possible explanation for the discrepancy between our (self-selected and comfortable) pace and the as-quickly-as-possible study undertaken by Tomas-Carus. According to the model of task prioritization (Yogev-Seligmann et al., 2012), the prioritization of tasks in dt tests is determined by factors that minimize danger and maximize pleasure. In line with this, research has shown that instructions regarding the prioritizing between mobility and cognitive subtasks can vary across dt studies and, thus, affect the test results (Bayot et al., 2018; Verghese et al., 2007).

TUGdt-S7 is the most challenging of the investigated dt conditions in the current study that is additionally supported by participants’ reported experience. All participants reported that TUGdt-S7 was more stressful and difficult than the other two TUGdt test conditions. This is in agreement with findings reported by Smith et al. (Smith, Cusack, et al., 2017) from an examination of different cognitive tasks carried out during straight-line walking. In line with this, under dt conditions, counting down by seven has been judged to be more challenging than naming animals (Hunter et al., 2018). Another study showed comparable results; of all of the dt conditions tested, counting backwards led to the greatest interference and highest dt cost for older adults (Goh et al., 2021). However, direct comparison of study results on dt interference of gait is problematic because the assessment protocol varies between studies, both in terms of task and in terms of gait conditions

Table 4 Gait Parameters by Direction Separately for Each TUG Test Conditions

TUG condition	Direction	Step duration (s) Median (min, max)	Double-stance duration (s) Median (min, max)	Single-stance duration (s) Median (min, max)	Step length (m) Mean (std) (min, max)	Step width (m) Mean (std) (min, max)
Single	Forward	0.56 (0.49, 0.67)	0.12 (0.04, 0.21)	0.44 (0.38, 0.53)	0.61 (0.10) (0.42, 0.87)	0.17 (0.05) (0.01, 0.28)
	Return	0.57 (0.48, 0.70)*	0.14 (0.02, 0.18)	0.45 (0.39, 0.54)	0.61 (0.09) (0.40, 0.80)	0.19 (0.04) (0.12, 0.28)*
Naming animals	Forward	0.60 (0.46, 0.86)	0.12 (0.04, 0.24)	0.48 (0.40, 0.64)	0.61 (0.09) (0.36, 0.88)	0.17 (0.04) (0.09, 0.25)
	Return	0.68 (0.50, 1.35)*	0.16 (0.04, 0.52)*	0.51 (0.40, 0.83)	0.58 (0.11) (0.37, 0.85)*	0.18 (0.04) (0.07, 0.27)
Months backwards	Forward	0.64 (0.44, 1.21)	0.14 (0.00, 0.61)	0.50 (0.42, 0.61)	0.58 (0.12) (0.27, 0.89)	0.19 (0.06) (0.10, 0.30)
	Return	0.68 (0.51, 1.39)*	0.16 (0.05, 0.56)*	0.52 (0.44, 1.11)*	0.56 (0.10) (0.34, 0.77)	0.19 (0.05) (0.08, 0.28)
Serial 7s	Forward	0.67 (0.52, 1.82)	0.17 (0.08, 0.42)	0.50 (0.39, 1.40)	0.56 (0.12) (0.30, 0.83)	0.18 (0.05) (0.03, 0.27)
	Return	0.67 (0.52, 2.86)	0.17 (0.09, 0.78)	0.50 (0.40, 2.08)	0.55 (0.09) (0.37, 0.74)	0.18 (0.04) (0.11, 0.27)

Note. Forward referring to the outward, before the turn, and return referring to going back, after the turn of the TUG. TUG = Timed Up-and-Go.
$^*p < .05$.

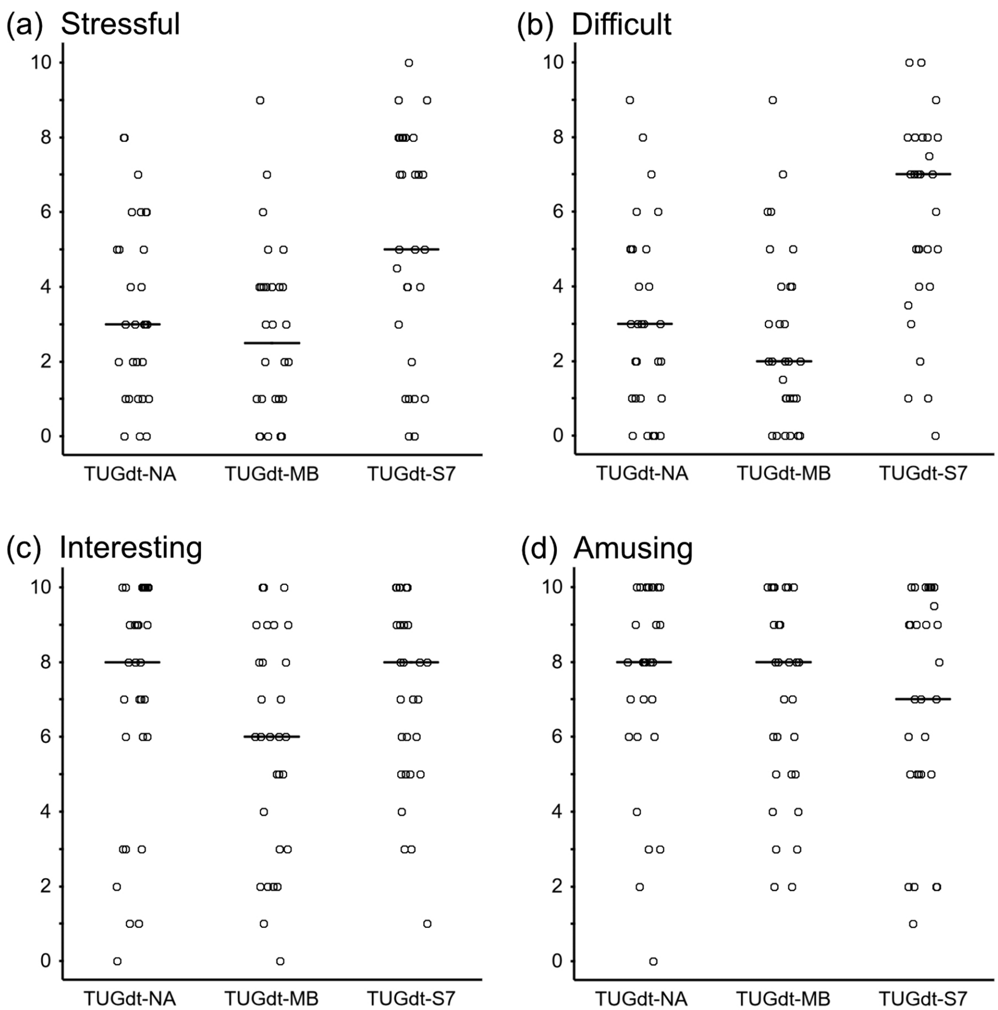

Figure 3 — Evaluation using a 0- to 10-point Likert scale of participant experience of the different types of TUGdt procedures (TUGdt-naming animals, TUGdt-months backwards, and TUGdt-serial 7s) according to the degree to which they were (a) stressful, (b) difficult, (c) interesting, or (d) amusing to carry out. *Note.* Horizontal lines indicate medians. TUGdt = Timed Up-and-Go dual-task test.

(Al-Yahya et al., 2011; Smith, Cusack, et al., 2017). Even within the same category of cognitive tasks, the complexity level can differ. For instance, mental tracking tasks such as subtraction can vary from counting backwards by one (Nielsen et al., 2018) to a more complex subtraction of counting backwards by seven (Coulthard et al., 2015).

Using TUG as the motor task for dt testing, instead of the more frequently used straight-line walking, has been viewed as advantageous. The complexity of the TUG subtasks (Bayot et al., 2018) can challenge executive functions to a greater degree than gait alone (Donoghue et al., 2012) and might thereby be more sensitive to executive dysfunction, which could be indicated by a prolonged execution time (Mirelman et al., 2014). However, there is a limited amount of research on interference of gait parameters during TUG. The only study found to have tested this involved older community-dwelling adults who were asked to perform as quickly as possible a TUGdt with a cognitive component of counting backwards by three (Smith, Walsh, et al., 2017). The results showed, in agreement with ours, a decrease for TUGdt in SL and increased stride time compared to TUGst. In contrast to our findings, no significant difference in DSD between TUGdt and TUGst was found, and no TUGdt gait interference was presented.

One limitation of our study is the modest sample size, which hindered an analysis of potentially relevant subcategories such as gender and age difference. Moreover, the sample may be viewed as somehow heterogeneous, as some of the assessment items showed that a small proportion of them had some mild "borderline" functional limitations. In the interpretation of the results, the characteristics of the participants also need to be considered, since all of them were community dwelling and participated in regular physical training, and 20 out of 30 had a university education. Another limitation is the lack of assessment of the concomitant dt interference on cognition, which may have added value to the results by enabling further analysis of the dt interference on cognition. One of the strengths of this study is that the methodology of extracting gait parameters has been shown to be valid and reliable (Åberg et al., 2021, 2022). Moreover, the present study design with a mean of six recorded steps per participant and condition further dampened the intraindividual variability of gait parameters. Thus, despite the limited number of participants and notwithstanding the strict Bonferroni correction of *p* values, several significant results were found.

To sum up, the results confirm that the investigated TUGdt conditions cause gait parameter changes of varying degrees. They reveal a slower walking speed caused by a combination of prolonged temporal gait parameters (SD, DSD, and SSD) and shorter steps. When comparing TUGdt conditions, the TUGdt-S7 showed the greatest interference, indicating that it was the most challenging. Given that the TUGst has been shown to be moderately related to cognitive ability, in particular, executive function (Herman et al., 2011), and that the difficulty of a dt test should be close to the threshold of the target population's capacity to provide an adequate attentional load, it may be concluded that the TUGdt-S7 might be most applicable for community-dwelling people, with a low degree of impairment, whereas TUGdt-NA and TUGdt-MB may be more suitable for those with cognitive limitations.

Acknowledgments

This research was supported by grants from the Promobilia Foundation and the Dementia Foundation, Sweden. The authors would like to thank Ylva Cedervall, Hanna Bozkurt Åhman, and Fredrik Olsson for their contribution to the data collection.

References

Åberg, A.C., Olsson, F., Åhman, H.B., Tarassova, O., Arndt, A., Giedraitis, V., . . . Halvorsen, K. (2021). Extraction of gait parameters from marker-free video recordings of timed up-and-go tests: Validity, inter- and intra-rater reliability. *Gait & Posture, 90,* 489–495. https://doi.org/10.1016/j.gaitpost.2021.08.004

Åberg, A.C., Olsson, F., Ahman, H.B., Tarassova, O., Arndt, A., Giedraitis, V., . . . Halvorsen, K. (2022). Corrigendum to "Extraction of gait parameters from marker-free video recordings of timed up-and-go tests: Validity, inter- and intra-rater reliability" [Gait Posture 90 (2021) 489–495]. *Gait & Posture, 94,* 195–197. https://doi.org/10.1016/j.gaitpost.2022.03.015

Åhman, H.B. (2021). *TImed up and go dual task tests for early detection of dementia disorder* [unpublished doctoral dissertation]. Uppsala University.

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews, 35*(3), 715–728. https://doi.org/10.1016/j.neubiorev.2010.08.008

Bayot, M., Dujardin, K., Tard, C., Defebvre, L., Bonnet, C.T., Allart, E., & Delval, A. (2018). The interaction between cognition and motor control: A theoretical framework for dual-task interference effects on posture, gait initiation, gait and turning. *Neurophysiologie Clinique, 48*(6), 361–375. https://doi.org/10.1016/j.neucli.2018.10.003

Beauchet, O., Dubost, V., Aminian, K., Gonthier, R., & Kressig, R.W. (2005). Dual-task-related gait changes in the elderly: Does the type of cognitive task matter? *Journal of Motor Behavior, 37*(4), 259–264. https://www.ncbi.nlm.nih.gov/pubmed/15967751

Bohannon, R.W. (2017). Test-retest reliability of measurements of hand-grip strength obtained by dynamometry from older adults: A systematic review of research in the pubmed database. *J Frailty Aging, 6*(2), 83–87. https://doi.org/10.14283/jfa.2017.8

Bohannon, R.W., & Williams Andrews, A. (2011). Normal walking speed: A descriptive meta-analysis. *Physiotherapy, 97*(3), 182–189. https://doi.org/10.1016/j.physio.2010.12.004

Borges Sde, M., Radanovic, M., & Forlenza, O.V. (2015). Functional mobility in a divided attention task in older adults with cognitive impairment. *Journal of Motor Behavior, 47*(5), 378–385. https://doi.org/10.1080/00222895.2014.998331

Brustio, P.R., Magistro, D., Zecca, M., Rabaglietti, E., & Liubicich, M.E. (2017). Age-related decrements in dual-task performance: Comparison of different mobility and cognitive tasks. A cross sectional study. *PLoS One, 12*(7), Article e0181698. https://doi.org/10.1371/journal.pone.0181698

Cao, Z., Hidalgo, G., Simon, T., Wei, S.E., & Sheikh, Y. (2021). OpenPose: Realtime multi-person 2D pose estimation using part affinity fields. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 43*(1), 172–186. https://doi.org/10.1109/TPAMI.2019.2929257

Cao, Z., Martinez, G.H., Simon, T., Wei, S.E., & Sheikh, Y.A. (2019). OpenPose: Realtime multi-person 2D pose estimation using part affinity fields. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 43*(1), 172–186. https://doi.org/10.1109/TPAMI.2019.2929257

Cedervall, Y., Halvorsen, K., & Aberg, A.C. (2014). A longitudinal study of gait function and characteristics of gait disturbance in individuals with Alzheimer's disease. *Gait & Posture, 39*(4), 1022–1027. https://doi.org/10.1016/j.gaitpost.2013.12.026

Cedervall, Y., Stenberg, A.M., Åhman, H.B., Giedraitis, V., Tinmark, F., Berglund, L., . . . Åberg, A.C. (2020). Timed up-and-go dual-task testing in the assessment of cognitive function: A mixed methods observational study for development of the UDDGait protocol. *International Journal of Environmental Research and Public Health, 17*(5), Article 1715. https://doi.org/10.3390/ijerph17051715

Christopher, A., Kraft, E., Olenick, H., Kiesling, R., & Doty, A. (2021). The reliability and validity of the timed up and go as a clinical tool in individuals with and without disabilities across a lifespan:

A systematic review. *Disability and Rehabilitation, 43*(13), 1799–1813. https://doi.org/10.1080/09638288.2019.1682066
Costa, R., Pompeu, J.E., Viveiro, L.A.P., & Brucki, S.M.D. (2020). Spatial orientation tasks show moderate to high accuracy for the diagnosis of mild cognitive impairment: A systematic literature review. *Arquivos de Neuro-Psiquiatria, 78*(11), 713–723. https://doi.org/10.1590/0004-282x20200043
Coulthard, J.T., Treen, T.T., Oates, A.R., & Lanovaz, J.L. (2015). Evaluation of an inertial sensor system for analysis of timed-up-and-go under dual-task demands. *Gait & Posture, 41*(4), 882–887. https://doi.org/10.1016/j.gaitpost.2015.03.009
Cullen, S., Borrie, M., Carroll, S., Sarquis-Adamson, Y., Pieruccini-Faria, F., McKay, S., & Montero-Odasso, M. (2019). Are cognitive subtypes associated with dual-task gait performance in a clinical setting? *Journal of Alzheimer's Disease, 71*(Suppl. 1), S57–S64. https://doi.org/10.3233/jad-181196
De Cock, A.M., Fransen, E., Perkisas, S., Verhoeven, V., Beauchet, O., Vandewoude, M., & Remmen, R. (2019). Comprehensive quantitative spatiotemporal gait analysis identifies gait characteristics for early dementia subtyping in community dwelling older adults. *Frontiers in Neurology, 10,* Article 313. https://doi.org/10.3389/fneur.2019.00313
Donoghue, O.A., Horgan, N.F., Savva, G.M., Cronin, H., O'Regan, C., & Kenny, R.A. (2012). Association between timed up-and-go and memory, executive function, and processing speed. *Journal of the American Geriatrics Society, 60*(9), 1681–1686. https://doi.org/10.1111/j.1532-5415.2012.04120.x
Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198. http://www.ncbi.nlm.nih.gov/htbin-post/Entrez/query?db=m&form=6&dopt=r&uid=1202204
Goh, H.T., Pearce, M., & Vas, A. (2021). Task matters: An investigation on the effect of different secondary tasks on dual-task gait in older adults. *BMC Geriatrics, 21*(1), Article 510. https://doi.org/10.1186/s12877-021-02464-8
Henry, J.D., Crawford, J.R., & Phillips, L.H. (2004). Verbal fluency performance in dementia of the Alzheimer's type: A meta-analysis. *Neuropsychologia, 42*(9), 1212–1222. https://doi.org/10.1016/j.neuropsychologia.2004.02.001
Herman, T., Giladi, N., & Hausdorff, J.M. (2011). Properties of the 'timed up and go' test: More than meets the eye. *Gerontology, 57*(3), 203–210. https://doi.org/10.1159/000314963
Hunter, S.W., Divine, A., Frengopoulos, C., & Montero Odasso, M. (2018). A framework for secondary cognitive and motor tasks in dual-task gait testing in people with mild cognitive impairment. *BMC Geriatrics, 18*(1), Article 202. https://doi.org/10.1186/s12877-018-0894-0
Jolliffe, I.T. (2002). *Principal component analysis* (2nd ed.). Springer.
Kahya, M., Moon, S., Ranchet, M., Vukas, R.R., Lyons, K.E., Pahwa, R., . . . Devos, H. (2019). Brain activity during dual task gait and balance in aging and age-related neurodegenerative conditions: A systematic review. *Experimental Gerontology, 128,* Article 110756. https://doi.org/10.1016/j.exger.2019.110756
Kvitting, A.S., Fallman, K., Wressle, E., & Marcusson, J. (2019). Age-normative MMSE data for older persons aged 85 to 93 in a longitudinal Swedish cohort. *Journal of the American Geriatrics Society, 67*(3), 534–538. https://doi.org/10.1111/jgs.15694
Manning, R.T. (1982). The serial sevens test. *Archives of Internal Medicine, 142*(6), Article 1192. https://doi.org/10.1001/archinte.1982.00340190148022
McIsaac, T.L., Lamberg, E.M., & Muratori, L.M. (2015). Building a framework for a dual task taxonomy. *BioMed Research International, 2015,* Article 591475. https://doi.org/10.1155/2015/591475
Meagher, J., Leonard, M., Donoghue, L., O'Regan, N., Timmons, S., Exton, C., . . . Meagher, D. (2015). Months backward test: A review of its use in clinical studies. *World Journal of Psychiatry, 5*(3), 305–314. https://doi.org/10.5498/wjp.v5.i3.305
Mirelman, A., Weiss, A., Buchman, A.S., Bennett, D.A., Giladi, N., & Hausdorff, J.M. (2014). Association between performance on timed up and go subtasks and mild cognitive impairment: Further insights into the links between cognitive and motor function. *Journal of the American Geriatrics Society, 62*(4), 673–678. https://doi.org/10.1111/jgs.12734
Montero-Odasso, M., Almeida, Q.J., Bherer, L., Burhan, A.M., Camicioli, R., Doyon, J., . . . Cognition, N. (2019). Consensus on shared measures of mobility and cognition: From the Canadian consortium on neurodegeneration in aging (CCNA). *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 74*(6), 897–909. https://doi.org/10.1093/gerona/gly148
Montero-Odasso, M., Pieruccini-Faria, F., Ismail, Z., Li, K., Lim, A., Phillips, N., . . . Camicioli, R. (2020). CCCDTD5 recommendations on early non cognitive markers of dementia: A Canadian consensus. *Alzheimer's & Dementia: Translational Research & Clinical Interventions, 6*(1), Article e12068. https://doi.org/10.1002/trc2.12068
Montero-Odasso, M.M., Sarquis-Adamson, Y., Speechley, M., Borrie, M.J., Hachinski, V.C., Wells, J., . . . Muir-Hunter, S. (2017). Association of dual-task gait with incident dementia in mild cognitive impairment: Results from the gait and brain study. *JAMA Neurology, 74*(7), 857–865. https://doi.org/10.1001/jamaneurol.2017.0643
Nielsen, M.S., Simonsen, A.H., Siersma, V., Hasselbalch, S.G., & Hoegh, P. (2018). The diagnostic and prognostic value of a dual-tasking paradigm in a memory clinic. *Journal of Alzheimer's Disease, 61*(3), 1189–1199. https://doi.org/10.3233/JAD-161310
Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*(2), 220–244. https://doi.org/10.1037/0033-2909.116.2.220
Peters, D.M., Fritz, S.L., & Krotish, D.E. (2013). Assessing the reliability and validity of a shorter walk test compared with the 10-meter walk test for measurements of gait speed in healthy, older adults. *Journal of Geriatric Physical Therapy, 36*(1), 24–30. https://doi.org/10.1519/JPT.0b013e318248e20d
Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society, 39*(2), 142–148. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1991946
Smith, E., Cusack, T., Cunningham, C., & Blake, C. (2017). The influence of a cognitive dual task on the gait parameters of healthy older adults: A systematic review and meta-analysis. *Journal of Aging and Physical Activity, 25*(4), 671–686. https://doi.org/10.1123/japa.2016-0265
Smith, E., Walsh, L., Doyle, J., Greene, B., & Blake, C. (2017). Effect of a dual task on quantitative timed up and go performance in community-dwelling older adults: A preliminary study. *Geriatrics & Gerontology International, 17*(8), 1176–1182. https://doi.org/10.1111/ggi.12845
Tomas-Carus, P., Rosado, H., Pereira, C., Marmeleira, J., Veiga, G., & Collado-Mateo, D. (2020). Differences between two types of dual tasks according to the educational level in older adults. *Archives of Gerontology and Geriatrics, 91,* Article 104216. https://doi.org/10.1016/j.archger.2020.104216
Vasconcelos, K.S., Dias, J.M., Bastone Ade, C., Vieira, R.A., Andrade, A.C., Perracini, M.R., . . . Dias, R.C. (2016). Handgrip strength cutoff points to identify mobility limitation in community-dwelling older people and associated factors. *The Journal of Nutrition, Health and Aging, 20*(3), 306–315. https://doi.org/10.1007/s12603-015-0584-y
Vaughan, R.M., Coen, R.F., Kenny, R., & Lawlor, B.A. (2018). Semantic and phonemic verbal fluency discrepancy in mild cognitive

impairment: Potential predictor of progression to Alzheimer's Disease. *J Am Geriatr Soc, 66*(4), 755–759. https://doi.org/10.1111/jgs.15294

Verghese, J., Kuslansky, G., Holtzer, R., Katz, M., Xue, X., Buschke, H., & Pahor, M. (2007). Walking while talking: Effect of task prioritization in the elderly. *Archives of Physical Medicine and Rehabilitation, 88*(1), 50–53. https://doi.org/10.1016/j.apmr.2006.10.007

Yogev-Seligmann, G., Hausdorff, J.M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement Disorders, 23*(3), 329–342. https://doi.org/10.1002/mds.21720

Yogev-Seligmann, G., Hausdorff, J.M., & Giladi, N. (2012). Do we always prioritize balance when walking? Towards an integrated model of task prioritization. *Movement Disorders, 27*(6), 765–770. https://doi.org/10.1002/mds.24963

Zirek, E., Ersoz Huseyinsinoglu, B., Tufekcioglu, Z., Bilgic, B., & Hanagasi, H. (2018). Which cognitive dual-task walking causes most interference on the timed up and go test in Parkinson's disease: A controlled study. *Neurological Sciences, 39*(12), 2151–2157. https://doi.org/10.1007/s10072-018-3564-2