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ORIGINAL ARTICLE

Task specificity impacts dual-task interference in older adults

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Abstract

Background Task prioritization is an important factor determines the magnitude and direction of dual-task interference in older adults. Greater dual-task cost during walking may lead to falling, sometimes causing lasting effects on mobility.

Aims We investigated dual-task interference for walking and cognitive performance.

Methods Twenty healthy, older adults (71 ± 5 years) completed three cognitive tasks: letter fluency, category fluency, and serial subtraction during seated and walking conditions on a self-paced treadmill for 3 min each, in addition to walking only condition. Walking speed, step length and width were measured during walking and each dual-task condition.

Results Comparing the percentage of correct answers in cognitive tasks across single and dual-task conditions, there was a main effect of cognitive task ($p = 0.021$), showing higher scores during letter fluency compared to serial subtraction ($p = 0.011$). Step width was significantly wider during dual-task letter fluency compared to walking alone ($p = 0.003$), category fluency ($p = 0.001$), and serial subtraction ($p = 0.007$).

Discussion During both fluency tasks, there was a cost for gait and cognition, with category showing a slightly higher cognitive cost compared to letter fluency. During letter fluency, to maintain cognitive performance, gait was sacrificed by increasing step width. During serial subtraction, there was a cost for gait, yet a benefit for cognitive performance.

Conclusion Differential effect of cognitive task on dual-task performance is critical to be understood in designing future research or interventions to improve dual-task performance of most activities of daily living.

Keywords Cognition · Gait · Fluency task · Dual-task cost

Introduction

Performing multiple tasks at the same time is an inevitable, high cognitive load situation (e.g. dual-task) that happens frequently during daily activities. These types of situations require attention to be shifted to adequately complete all tasks. Poor performance during dual-tasking is related to falls in older adults [1], and falls may lead to reduced functioning and mental health, including anxiety and depression, and even mortality [2]. The additional cognitive load can affect performance through several potential mechanisms. The ability to allocate and shift attention is an important component of dual-task performance. According to the limited capacity theory, performance decrements will occur when one or both tasks' demands exceed the available resources [3]. Bottleneck theory states that similar tasks will compete using the same processing pathways, yet only one stimulus can pass through a channel for processing at a time [4]. According to the time-sharing hypothesis, the amount of resource overlap between the two tasks may determine the amount of interference between tasks [5].

During dual-task situations, there is a need to manage the interference and switching between competing tasks. Furthermore, depending on the processing capacity required for each task, performance may enhance or deteriorate while tasks are being performed simultaneously compared to while being done separately. This has been called dual-task interference or dual-task effect (DTE) [6]. Evaluating

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the respective gait and cognitive DTE against each other can reveal the differences in the pattern of interference for each task individually. The magnitude and direction of DTE are influenced by task prioritization, which affects attention allocation [7]. DTE is quantified by dual-task cost, which estimates the amount performance is enhanced or deteriorated while performing two tasks concurrently compared to separately.

It is important to acknowledge how the nature of tasks involved will influence the interaction between tasks. Research most commonly uses walking or standing as the primary motor task [8–11]. Common secondary cognitive tasks include memory tasks [12, 13], responding to an auditory prompt [14], serial subtraction [15, 16], or verbal fluency tasks [17]. Of those mentioned, serial subtraction by 7′s or 3′s has been used most often [18, 19], and performance is influenced by working memory, education level, and individual computation ability [20]. Another popular secondary task is verbal fluency (e.g., list as many animals as you can), which requires strong verbal ability and executive function, as well as memory [21]. Furthermore, gait and balance require a high level of cognitive input in older adults [22]. Depending on the task combination and cognitive resources required for task completion, DTE varies. It is critical to understand how differing secondary, cognitive tasks may cause DTE while performing a primary task such as standing or walking.

Thus, the primary objective of this study was to determine DTE between the primary task of walking and differing secondary, cognitive tasks. Secondary tasks used were letter fluency (name as many words as possible that start with a given letter), category fluency (name as many words as possible that belong to a given category), and serial subtraction (subtractions by threes, starting from a three-digit number). To accurately interpret DTE, both tasks were assessed in single-task and dual-task conditions in a sample of healthy, older adults. It was hypothesized that older adults' task performance would reveal deficits or improvement based on the nature of the secondary cognitive task in the high cognitive load situation. Due to the additional load in the dual-task condition, we hypothesized that slower speed, shorter and wider steps, as well as more errors for cognitive tasks, might be observed in dual-task conditions compared to the single-task condition.

Materials and methods

Participants

As this is a secondary analysis of a data set, the participants and methods have been reported previously [23]. Twenty older adults (71 ± 5.0 years, 1.67 ± 0.11 m, 73.40 ± 17.4 kg, 27.0 ± 4.4 kg/m^2, 16.35 ± 2.6 years education) were recruited and consented to participate in this study. Older adult participants were recruited through senior wellness centers in the community, and were included if they were physically active without any neurological or orthopedic disorders that would affect participants' ability to complete the experimental tasks. All procedures were reviewed and approved by the University's Institutional Review Board. After written consent was obtained, demographic data and medical history, for screening purposes, were collected for each participant.

Apparatus and procedure

Participants attended two visits. During the first visit and after the screening procedure, participants completed three cognitive tasks while seated (single-task): letter (name as many words as possible that start with a given letter) and category fluencies (name as many words as possible that belong to a given category), and serial subtraction by 3′s starting from a three-digit number. Tasks were presented randomly. Details of the procedures have been previously published and was briefly stated below [23]; non-optic flow data are used in the current analysis.

During the category fluency task, participants were asked to perform three different category tasks for a total of 3 min (1 min for each letter) per visit. Categories were grouped as easy, medium, and hard categories (randomized between trials), which was determined by the researchers. They were instructed not to repeat words, use synonyms, and/or proper nouns. During the letter fluency task, participants were asked to perform three different letter tasks for a total of 3 min (1 min for each letter) per visit. Letters were grouped by difficulty so that each grouping contained two letters that were considered easy and one letter that was considered moderate [24]. They were instructed not to repeat words, use synonyms, and/or proper nouns. Letter groupings were randomized between visits. During the serial subtraction task, participants were asked to subtract a three-digit number by three continuously for 1 min. At the end of the minute, subjects were immediately given a new three-digit number. They did this a for three times, 1 minute each, for a total of 3 min. Starting numbers were chosen so that each number had a different starting subtraction pattern.

During the second visit, all participants walked on a self-paced treadmill at their normal pace while lower-extremity kinematic data were recorded (Nexus, Vicon, Oxford, UK; 100 Hz). The self-paced treadmill (Bertec Corp., Columbus, OH) automatically adjusted to the subject's speed via real-time feedback [25, 26]. A 5-min adaptation period to the treadmill was provided before starting any experimental conditions. All participants were asked to wear a form-fitting suit, and retroreflective markers were placed on the toe, heel, and malleolus of each foot. Subjects were required to wear a safety harness to prevent falls (Solo-Step, Inc., North Sioux City, SD) while walking on the treadmill. For all conditions, subjects wore headsets to record their responses while walking.

Once participants adapted to walking on a self-paced treadmill, they were asked to perform the same cognitive tasks that were completed during the first visit. In addition, a walking-only trial was randomized within the dual-task conditions. Subjects walked on a self-paced treadmill for 3 min for each of the three tasks (dual-tasks) and for the walking only (single-task) condition, for a total of four walking conditions. A break was provided between each of the cognitive conditions to prevent fatigue. All conditions were presented in a randomized order and no instruction for task prioritization was given.

Data analysis

The percentage of correct answers for each cognitive task during seated and walking conditions was determined. For fluency tasks, errors were counted as the use of same root words, repeating words, synonyms, proper nouns, or words not fitting the category or letter. For the arithmetic task, errors in subtraction were counted.

For the assessment of gait performance speed, step length, and step width were calculated [23]. Step length was determined as the anterior–posterior distance between contralateral heels at the moment of heel contact. Step width was calculated as the medio-lateral distance between heel markers at the moment of heel contact. The average speed, step length and step width from each of the three conditions for each subject were utilized for analyses. Mean values were then visually inspected and outliers were identified and removed. The absolute deviation around the median was used for detecting outliers [27], which is not sensitive to sample size. Decision criteria were defined as follows (moderately conservative):

$$M - 2.5 * \mathrm{MAD} < x_i < M + 2.5 * \mathrm{MAD}$$

where M was the median and MAD was the median absolute deviation. Final data used for statistical analysis can be found in supplemental data 1. All calculations of gait variables were performed using custom Matlab (The MathWorks, Natick, MA) programs.

Dual-task interference was quantified using DTE. This was calculated for each gait parameter and cognitive task performance during the three, dual-task walking conditions compared to walking alone or seated, respectively. DTE was expressed as a percent change in performance during dual-task relative to single-task conditions using the following equation:

$$\mathrm{DTE} = \frac{\text{Difference in DT and ST performance}}{\text{ST performance}} \times 100\% \quad (1)$$

where DT is dual-task condition and ST is the single-task condition. Negative DTE values indicated performance deterioration in dual-task compared to single-task, while positive values reflect improvements in the dual-task performance compared to single-task.

Statistics

Data were visually inspected for normality using histograms. Normally distributed data allowed the use of one-way, repeated measure ANOVAs to compare each gait parameters' mean values during the four walking conditions (walking only and three dual-task conditions). A two-way repeated measure ANOVA (2 × 3) was used to compare the percentage of correct answers between the three cognitive tasks (letter fluency vs. category fluency, vs. serial subtraction) and two condition levels (seated vs. walking). Tukey post hoc tests were conducted to determine significant differences between levels. Data were analyzed with SPSS version 23 (IBM Corp., Armonk, New York). Statistical significance was set at $\alpha = 0.05$. Visual analysis of the pattern of DTE in gait and cognitive performance was performed by plotting the negative and positive values of gait and cognitive DTE against each other [7].

Results

Mean and standard deviation of speed, step length, and step width during all walking conditions are shown in Table 1. There was a significant difference in step width among walking conditions ($p = 0.001$). Post-hoc testing revealed that step width was significantly wider during dual-task letter fluency compared to walking alone ($p = 0.003$), dual-task category fluency ($p = 0.001$), and dual-task serial subtraction ($p = 0.007$) (Fig. 1). No differences were found for speed or step length.

The 2 (condition) × 3 (task) ANOVA for cognitive performance revealed a significant main effect of task ($F_{1.15,23.76} = 5.89$, $p = 0.021$). Post-hoc testing revealed that the percentage of correct answers was greater for letter fluency than serial subtraction across conditions ($p = 0.011$; Fig. 2). Although the cognitive performance during letter fluency was better than category fluency task, it failed to reach the statistical significance ($p = 0.083$). No main effect of condition (single vs. dual-task) was found.

Gait and cognitive DTE plotted on the same grid (Fig. 3). During both fluency tasks, there was a cost for both gait and cognitive performance; while, the cost for the cognitive task during letter fluency was minimal. However, during

Table 1 Mean (standard deviation) of speed, step length, and step width during the walking only (single-task) and each dual-task condition

	Single-task: walking only	Dual-task: category fluency	Dual-task: letter fluency	Dual-task: serial subtraction	*p* value[1]	Partial eta squared
Speed (m/s)	1.21 (0.17)	1.18 (0.21)	1.17 (0.19)	1.16 (0.2)	0.61	0.03
Step length (cm)	57.14 (8.28)	56.39 (7.75)	55.72 (7.19)	55.27 (7.45)	0.29	0.07
Step width (cm)	15.99 (3.98)	15.97 (3.93)	17.30 (3.83)	16.25 (4.36)	0.001	0.25

[1]*p* values from repeated measure analysis of variance

serial subtraction, there was a cost for gait, yet the dual-task enhanced cognitive performance.

Discussion

The aim of the present study was to examine the effect of different types of cognitive tasks on dual-task interference in older adults. It was expected that based on the differences in the nature of cognitive tasks, dual-task interference would vary. We hypothesized that dual-task conditions might lead to a slower speed and shorter and wider steps during dual-task conditions. For cognition, more errors were expected in dual-task conditions compared to the single-task condition. This hypothesis was supported in part as step width was wider during letter fluency. Moreover, we observed that DTE was altered with different tasks. Cognitive performance was enhanced during the dual-task when serial subtraction was being performed; however, this was associated with a cost to gait. On the other hand, both fluency tasks had a cost for both gait and cognition during dual-tasking.

Changes in performance during dual-tasking compared to the single-task were expected; the significant findings were during the performance of the letter fluency task, specifically for step width. During dual-task letter fluency, step width became wider compared to walking only and the other dual-task conditions (serial subtraction and category fluency), and coincided with a greater percentage of correct answers. A potential factor leading to wider steps (compensatory strategy) in older adults could be related to the competition for executive control between balance during gait and the letter fluency task. Lateral balance has been reported to be connected to fall risk [28], and is mainly associated with the adjustment of step width, rather than length and speed [29]. It is possible that to correctly complete the letter fluency task, more attention was given to the cognitive task rather than lateral balance. Therefore, the step width widened to protect balance, allowing more attention to be focused on the cognitive fluency task.

None of the gait measures significantly changed during serial subtraction and category dual-task conditions compared to the walking only condition. Participants have perceived a verbal fluency task as more difficult than subtracting 7 from 100 [30]. Yet, compared to a verbal fluency cognitive task, an arithmetic cognitive task may have a greater impact on gait function (i.e. increasing step variability) [31]. However, the arithmetic task in our study was serial subtraction by three, which might not be demanding enough to affect gait function. Moreover, the letter fluency task appeared to compete with gait more so than category fluency. Healthy people can generate more words on category than letter fluency tasks, pointing out that the category fluency task may be less demanding than letter fluency [17]. Furthermore, vocabulary knowledge and lexical access are the main determinants of category, while, the executive function may play a more determinant role on letter fluency as well as gait.

Evaluating the respective gait and cognitive DTE against each other could be helpful to reveal the differences in the individual pattern of interference for each task [7]. In this study, when the costs for both gait and cognition were plotted against each other, it was revealed that serial subtraction performance was enhanced under the dual-task condition. This finding is in line with the report of a dual-task benefit for a cognitive task, yet a cost for gait velocity, being related to a prioritization strategy [15]. Our findings suggested that allocation of attention and prioritization was different across tasks and between conditions, despite the fact that we did not provide instructions to prioritize one task over another. Older adults had positive DTE for cognition during serial subtraction, indicating that the dual-task condition facilitated cognitive performance. However, this improvement in serial subtraction coincided with a cost for each of the three gait measures, revealing that older adults might have prioritized the cognitive task over walking. During fluency tasks, we observed a concurrent cost for both cognition and gait, which is in line with a previous study showing the mutual cost of gait and cognition across different ages [32]. It has been suggested that verbal fluency tasks share complex neural networks which are interlinked with gait control [33] and cognitive task demands may be enough to interfere with these networks and lead to disturbed gait [34]. The phonological loop and the visuospatial sketchpad

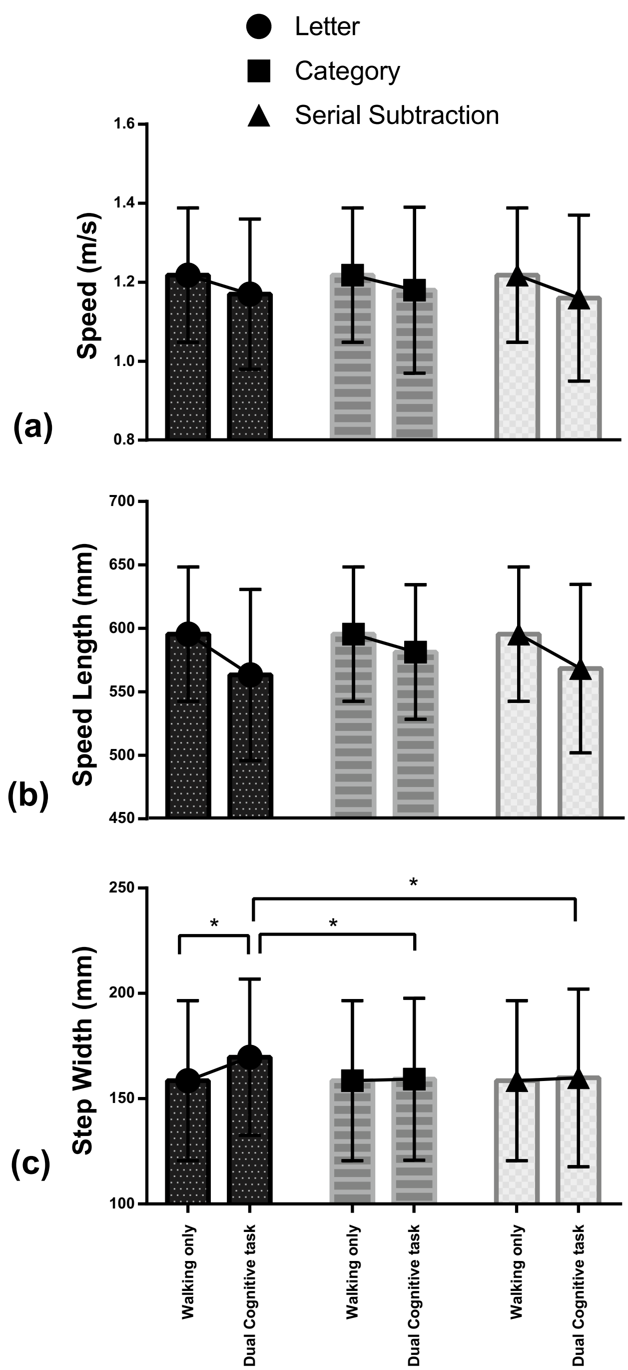

Fig. 1 Comparison between walking only and dual-task conditions for **a** speed, **b** step length, and **c** step width. Dual-task conditions included walking while doing a concurrent cognitive task, these included: letter fluency (circle), category fluency (square), and serial subtraction by 3 (triangle). Horizontal bars note significant differences, which were found from post-hoc testing after the one-way repeated measure ANOVA

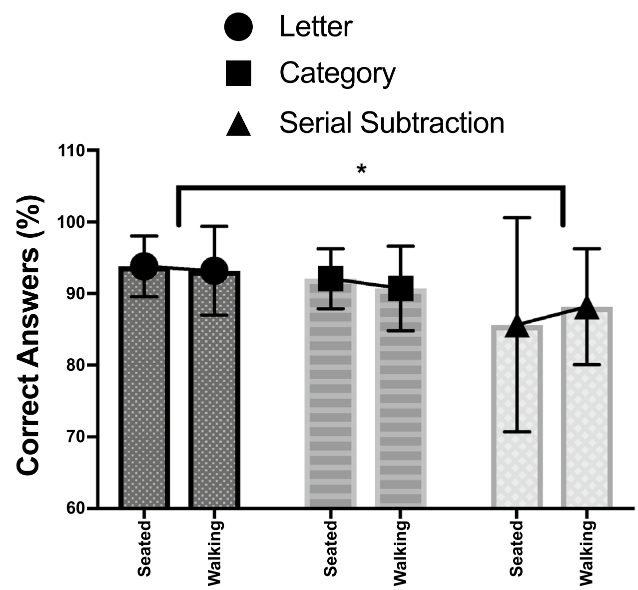

Fig. 2 Comparison of the cognitive scores between seated and walking conditions for each cognitive task: letter fluency (circle), category fluency (square), and serial subtraction by 3 (triangle). Cognitive scores were calculated as the percentage of correct answers. Significant differences are noted with the horizontal bar, which were found from post-hoc testing after the two-way repeated measure ANOVA

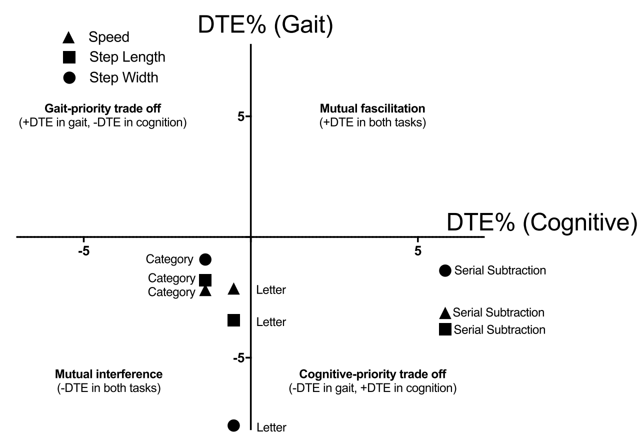

Fig. 3 DTE was calculated for all gait variables and cognitive tasks as a percent change in performance during dual-task relative to single-task conditions. Negative values on the axes indicate deterioriation of the task under dual- vs. single-task conditions, while positive values on the axes show a benefit of performing the task under dual- vs. single-task conditions

(two subsystems of working memory) are identified as the main associates of fluency performance [21]. Considering the key role of the hippocampus in regulating gait function [35] and the hippocampal atrophy associated with memory decline in normal aging [36], the observed cost in the concurrent gait and fluency tasks was expected.

Increased step width during concurrent letter fluency performance, compared to walking only and the other dual-task conditions (serial subtraction and category fluency), coincided with a greater percentage of correct answers. These findings are attributed to the fact that letter fluency can differentially affect gait performance compared to category fluency and serial subtraction, and might reveal changes in the early stages of cognitive or physical impairment in more vulnerable populations, including older adults who subsequently develop dementia [37]. Moreover, individual factors such as motor and cognitive abilities, balance confidence and even perceived importance of each task are important factors that can influence the pattern of dual-task interference and should be considered in future studies. For future development of interventions, it may be important to know which cognitive tasks (i.e., letter fluency) may have a greater effect on the motor task to adjust the challenge of an intervention program.

There are several limitations to this study. First, the practice effect on cognitive dual-task may exist as the single-task condition was always run in the first session. Unfortunately, we needed to do a full visit session for a cognitive single task and it was not possible to perform them on the same day. However, walking only trials (single task for gait measures) were randomized within the dual-task trials in the second visit. Second, it should be acknowledged that the use of a self-paced treadmill needs a sufficient adaptation period, which could be variable for each individual. Therefore, using a 5-min adaptation period for all participants may not have been a sufficient length of time for older adults to adapt. Third, older adults in this study were relatively healthy, active, and aged ~ 70 years old which would be considered "young-old". These participant characteristics may limit generalizability. Future studies may want to consider a cohort of older adults aged 85+ years as it has been suggested to reveal more age-related decrements [38] and they are the fastest-growing segment of the population. Fourth, investigating older adults that appear to be at risk, either due to cognitive or physical performance, would be of interest in the future, subjects could be divided between those that scored lower versus higher on cognitive and physical function screening tests as individual characteristics may play a role in performance. This could be especially useful given the link between gait and cognitive functioning, as well as gait and physical ability. Fifth, we had sufficient evidence to reject the null for our findings with step width, but not enough evidence for step length and speed. Post hoc power analysis can be found in supplemental material 2.

Conclusion

The findings of this research demonstrated that the type of concurrent cognitive task may have an influence on dual-task interference. Serial subtraction showed better performance during dual-task compared to single-task, which might be due to allocating more attentional resources to the computation rather than walking. However, shared demands of executive function and working memory in the fluency tasks while walking led to cost for both task's performances. Dual-task changes in one task in relation to the other concurrent task could be informative for potential tradeoff strategies, which are important in designing targeting intervention programs in older adults. Therefore, considering the interactions between concurrent tasks is necessary for treatment purposes in clinical practice.

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Authors' contributions FF: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Writing—original draft; Writing—review and editing. DMV, and HJK: Methodology; Writing—review and editing. JY and JBB: Conceptualization; Funding acquisition; Methodology; Project administration; Resources; Supervision; Writing—review and editing.

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Availability of data and material As supplemental data.

Compliance with ethical standards

Conflicts of interest The authors have no conflicts of interest to declare.

Ethical approval All procedures were reviewed and approved by the University's Institutional Review Board.

Informed consent After written consent was obtained, demographic data and medical history, for screening purposes, were collected for each participant.

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