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Characteristics of stepping over an obstacle in community dwelling older adults under dual-task conditions

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Abstract

Previous research suggests that older adults may have difficulty attending to simultaneous tasks. This study was conducted to determine how concurrent performance of a secondary cognitive task influences walking and stepping over an obstacle in community dwelling older adults. Twenty-one men and women with a mean age of 73.4 years (S.D. = 5.3) participated in the study. Subjects performed a gait task both alone (single-task condition) and in combination with a cognitive task that involved reciting numbers (dual-task condition). In the gait task, each subject walked at his/her fastest speed along a 10-m walkway and stepped over an obstacle designed to simulate a door threshold. Paired *t*-tests were used to compare gait parameters (10 m gait speed, gait speed during obstacle approach and negotiation, medial-lateral center of pressure excursion and velocity during obstacle negotiation, foot clearance over the obstacle, step length and foot position relative to the obstacle) and cognitive task performance under single and dual-task conditions. Toe-obstacle distance was greater and obstacle-heel distance was reduced under dual-task conditions. Performance of the remaining gait parameters did not change with the addition of a secondary cognitive task. Cognitive task performance decreased under dual-task conditions. These community dwelling older adults demonstrated minimal or no change in measured gait parameters during simultaneous performance of a cognitive task. The observed decrement in cognitive task performance suggests that subjects may have placed a higher priority on gait performance.

Keywords: Dual-task; Attention; Gait; Obstacle avoidance

1. Introduction

Falls among older adults are often complex in nature, resulting from a combination of factors [1–4]. Researchers have suggested that failing to avoid environmental hazards and tripping are associated with falls in community dwelling older adults [5,6]. Falls often result in injury and loss of independence in performing everyday activities and are a leading cause of disability among older adults [2,7–9]. Identification and understanding of the risk factors of falls are essential to developing effective interventions aimed at reducing falls and maintaining independence in older adults.

Balance deficits and impaired cognition are among several identified risk factors for falls [2,4,10,11]. Research using the dual-task paradigm provides evidence of a relationship between balance and cognition [12–15]. Compared to young adults, older adults demonstrate decreased postural stability and/or cognitive task performance when these tasks are performed concurrently [12,14–18] and they are less successful in avoiding a suddenly appearing 'virtual obstacle' in their gait path while performing a concurrent reaction time task [19]. Older adults who require significantly more time to perform simple simultaneous manual and mobility tasks or those who stop walking during a conversation are more likely to experience falls [20,21].

Previous research of dynamic balance activities using the dual-task paradigm has focussed on the interference effects associated with performance of a manual task or conversation concurrently with walking [20,21] and performance of simple reaction time tasks concurrently with obstacle-avoidance [19]. Consistent with the demands on postural stability encountered in everyday life, meaningful investigation of the effects of concurrent attentional demands on balance must include dynamic physical tasks along with more complex continuous cognitive processing tasks. Knowledge of some of the kinematic and kinetic

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changes that may occur in gait with performance of concurrent tasks may contribute to better identification of deficits and possible risks associated with these tasks.

The study described here provides information on the ability of community dwelling older adults to modify their gait and/or cognitive strategies for stepping over a stationary obstacle under dual-task conditions. Previous research emphasizes avoidance of suddenly appearing 'virtual obstacles' under dual-task conditions while walking at a comfortable, or self-selected, speed [19,22]. The use of a real obstacle placed within view in this study allowed subjects to adjust their gait while performing a concurrent cognitive task and also posed the risk of tripping if foot clearance was inadequate. Common everyday tasks, such as talking while walking outdoors or through a doorway, require adjustment of gait prior to reaching an obstacle to successfully avoid it without stopping or dramatically altering gait immediately prior to the obstacle. Gait performance at each subject's fastest speed provides a greater challenge than self-selected gait speed and also affords insight into how dual-task performance may be affected when older adults are walking quickly. The cognitive task used in this study simulates common tasks, such as engaging in conversation, that require selectively attending to relevant stimuli and inhibiting irrelevant information for a continual intake of information followed by a response.

The primary purpose of this study was to determine how concurrent performance of a continuous secondary cognitive task influences performance characteristics of fast walking and stepping over an obstacle in community dwelling older adults. Specific performance characteristics investigated included gait speed, step length, foot distance from the obstacle, magnitude and variability of vertical foot clearance over the obstacle and medial-lateral center of pressure (COP) excursion and COP velocity of the trail (stance) limb as the lead (swing) limb steps over the obstacle. A secondary purpose of this study was to describe strategies community dwelling older adults use during simultaneous performance of a continuous cognitive task and walking and stepping over an obstacle. We hypothesized that concurrent performance of a continuous cognitive task with fast walking and stepping over an obstacle would result in performance decrements of both the physical and cognitive tasks.

2. Materials and methods

2.1. Subjects

Twenty-two community dwelling older adults volunteered and 21 individuals (15 women, six men) between 67 and 88 years of age (mean: 73.4; S.D.: 5.3 years) completed testing. Subject characteristics are presented in Table 1.

Subjects were men and women who: were 65 years of age or older and reported themselves to be in 'good health'; were able to step over a door threshold unassisted and walk over level surfaces without use of an assistive device; scored a minimum of 25 on the Mini Mental State Exam (MMSE) [22,23]; had no history of neurological or cardiovascular problems; had not experienced any major changes in medications or health status over the previous month; were English speaking; and had no speech disorders. All subjects signed an informed consent form approved by the Institutional Human Subjects Review Board.

Table 1
Subject characteristics

Characteristics	Mean (S.D.)	Range
Age (years)	73.4 (5.3)	67–88
Education (years)	16.4 (2.1)	13–21
MMSE score	29.8 (0.5)	28–30
Visual edge contrast*	19.0 (1.7)	16–23

* Poor visual edge contrast <16 [3,24].

Subjects were excluded if they reported difficulty maintaining their balance while walking or responded that their balance was 'poor'; had current medical problems that could result in pain with repeated trials (reported as > 5 on a 0–10 pain scale); reported visual loss not corrected by lenses or were unable to detect a visual edge contrast of greater than or equal to 16 db on the Melbourne Edge Test (MET) [3,24]; experienced difficulty hearing an audio tape recording of numbers; or were unable to achieve 90% baseline accuracy for the cognitive task involving listening and responding to an audio tape recording of single digit numbers.

The primary investigator conducted a telephone interview to screen potential subjects for inclusion and exclusion criteria, health status and demographic information. The MMSE, MET and subject ability to perform a continuous cognitive task involving listening and responding to an audio tape recording of single digit numbers were assessed on the day of testing due to the nature of these criteria. One subject was excluded because of failure to meet the criterion for the cognitive task. Subjects were instructed to wear comfortable clothing and customary footwear for testing.

2.2. Instrumentation

The laboratory set-up is diagrammed in Fig. 1. An obstacle designed to simulate the dimensions of an indoor/outdoor threshold was placed adjacent to a forceplate embedded in a 10-m walkway. The obstacle was a piece of wood painted brown, 0.91 m in width, 0.15 m in depth and 0.02 m in height, with a door threshold secured and centered on the top of the wood. The highest point of the obstacle was 0.04 m at the center. The obstacle was positioned just past the far edge of the forceplate, so the subject stood on the forceplate with the one limb while stepping over the obstacle with the other limb.

A Bertec Model 4060A (Bertec Corp., Worthington, OH) force plate mounted in the floor was used to measure displacement of the medial-lateral COP of the trail limb as the

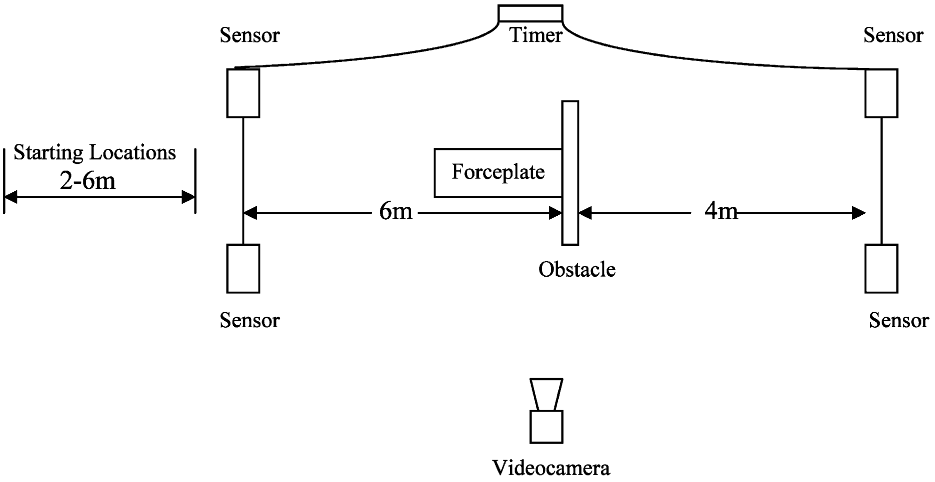

Fig. 1. Diagram of laboratory set-up.

subject stepped over the obstacle with his/her lead foot. DATAPAC 2000 (Run Technologies, Laguna Hills, CA) software was used to acquire force platform data at a sampling rate of 200 Hz.

A Panasonic AG-456 S-VHS videocamera, located on each subject's dominant side and placed on a tripod 0.30 m from the floor and perpendicular to the walkway, was used to record foot clearance over the obstacle and gait speed during subject approach and negotiation of the obstacle. A field of view of 3 m and a picture rate of 60 frames per second were used [25] for a resolution of 0.0075 m. A Panasonic VHS videocassette player/recorder and the Motus Motion Measurement System, Version 4.3 (Peak Performance Technologies, Inc., Inglewood, CO) were used for digitizing marker locations into coordinate data. A customized computer program by Motionsoft© (Chapel Hill, NC) was used to calculate linear distances and velocity from the 2D coordinate data. A Butterworth low-pass digital filter with a cut-off at 6 Hz was used for data smoothing, as determined by residual analysis.

Infrared sensors connected to a millisecond timer and placed at the start and end of the walkway were used to measure the time for each subject to walk the length of the 10 m walkway.

2.3. Procedures

Prior to testing, the MMSE, MET and baseline cognitive test were administered to each subject. Subjects were seated comfortably in a chair with armrests in a quiet room to determine baseline performance of the secondary cognitive task, which is called the '1-back' task. Subjects listened and responded to auditory tapes originally developed for the Paced Auditory Serial Addition test (PASAT) [26]. The PASAT audiotapes randomly present numbers from one to nine at four rates, with one number presented every 2.4, 2.0, 1.6 or 1.2 s. Each subject was instructed to respond to each number presented by stating the previously presented number and to continue to respond to each presented number by stating the previous number until told to stop [26]. For instance, if the numbers '7-9-2' were presented, the subject was to respond '7' immediately after the 9 was presented and '9' immediately after the 2 was presented.

Each subject was given a brief practice trial consisting of verbal presentation of three numbers. Following practice, subjects performed the 1-back task beginning with the rate of one number every 2.4 s and progressing to each of the faster rates. Each of the presentation rates was performed for 30 s. The investigator terminated the 1-back baseline testing when the subject's performance fell below 90% accuracy or he or she successfully completed the fastest rate (1.2 s). Each subject's baseline rate for the 1-back task was determined as the fastest presentation rate for which he or she was able to attain at least 90% accuracy. Subjects had brief rest periods after each 30-s test.

Each subject was asked to kick a stationary ball after a 4-m approach on the day of testing to determine foot dominance. The foot each subject used to kick the ball was defined as his/her dominant foot [27]. Height and weight information were obtained for each subject and two flat reflective markers, 22 mm in diameter, were placed on the shoes of both the dominant and non-dominant lower extremities of each subject prior to practice trials. On the dominant foot, markers were positioned on the lateral sole of the shoe directly below the fifth metatarsal head and on the most posterior-lateral aspect of the sole of the shoe at the heel. Markers were placed on the medial aspect of the non-dominant foot on the sole of the shoe directly below the first metatarsal head and on the most posterior-medial aspect of the sole of the shoe at the heel. A 25 mm spherical marker was attached to an 8 cm rod and then to a belt. The belt was placed around each subject's waist and secured so the marker was positioned over the lumbar spine at the approximate level of the iliac crests and extended 8 cm posteriorly. A small dictaphone tape recorder attached to a string was placed around the subject's neck for ease and clarity in hearing the numbers for the 1-back cognitive task. The presentation rate of the numbers on the audiotape during dual task conditions was at the fastest rate achieved during baseline testing of the 1-back task. Each subject's verbal responses on the 1-back test were recorded by hand during each dual-task trial.

Two practice trials of the gait task and stepping over an obstacle were performed. The tape recorder was worn for practice and single-task test trials for consistency with dual-task test trials in which the tape recorder was turned on for the 1-back task. The walkway was 10 m in length, with the obstacle placed 6 m from the time sensor at the beginning of the walkway. Subjects walked in the same direction for all trials and the dominant foot was the lead foot for stepping over the obstacle. An assistant stood next to the obstacle during all practice and test trials to help protect against trips or falls. Subjects initiated all trials at randomized locations between 2 and 6 m preceding the time sensor marking the beginning of the 10-m walkway. The randomized starting locations varied by 0.5 m increments to prevent prior planning of stepping sequence by the subjects and to allow performance of the 1-back task to begin prior to the beginning of the 10 m walkway. All subjects followed the same randomized sequence of starting locations for consistency. Gait test trials consisted of one single task and one dual task condition. On single task trials, subjects were instructed to walk as fast as they comfortably could for the length of the walkway and step over the obstacle. Dual task trials consisted of performance of the gait task concurrently with the 1-back cognitive task. Subjects were instructed to 'Walk as fast as you are comfortable with for the entire length of the walkway and step over the obstacle, while also responding to the numbers recited on the tape just as you did before, saying out loud the previously reported number. Try to be as accurate as possible when reporting the numbers.' Instructions were repeated for each of the first four trials and then every third trial until the end of testing. The initial starting trial condition was counterbalanced between the single or dual-task condition and remaining trials were alternated by condition for a total of 15 trials of each. Trials in which the subject stepped over the obstacle with the non-dominant foot were excluded from analysis and subjects were asked to repeat the trial. Subjects were not initially instructed to lead with the dominant foot when stepping over the obstacle; however, if a trial had to be repeated three times because of leading with the non-dominant foot, the subject was instructed to lead with the dominant foot. Subjects were not explicitly informed of trial numbers or when they were repeating a specific trial and were encouraged to rest as needed during testing.

2.4. Data reduction and analysis

Force platform data were exported from DATAPAC 2000 in ASCII format, then imported into a customized computer program by Motionsoft©. The customized software was used to calculate the COP variables. The medial-lateral COP excursion (COPE) was defined as the difference between the minimum and maximum medial-lateral COP location for the length of time the trail foot was in contact with the force plate. Mean velocity of the COP in the medial-lateral direction (COPV) was also calculated for the length of time the trail foot was in contact with the force plate.

Videographic 2D coordinate data were imported into a customized software program by Motionsoft© and transformed into linear vertical distance and horizontal linear velocity data using the linear distance scaling factor in the Motus Motion Measurement System, Version 4.3 (Peak Performance Technologies Inc.). Foot clearance (FC) was defined as the minimum vertical clearance between the top of the obstacle and the lowest marker on the lead foot as it passed over the top/center of the obstacle [27]. The marker placed on the posterior-lateral aspect of the sole of the shoe at the heel was used for calculation of foot clearance because it demonstrated minimal average clearance for both the single and dual-task trials. Step length (SL) was calculated using the horizontal locations of the heel markers on the trail foot at heel strike prior to the obstacle and the lead foot at heel strike after crossing the obstacle. Toe-obstacle distance (TO) was calculated as the horizontal distance between the marker placed below the first metatarsal head on the trail foot and the front edge of the obstacle during obstacle crossing. Obstacle-heel distance (OH) was calculated as the horizontal distance between the rear edge of the obstacle and the heel marker on the lead foot measured at heel strike after crossing the obstacle. The time measured by the infrared sensors to walk the 10-m path was used to calculate overall 10 m gait speed (OGS). Crossing gait speed (CGS) was measured as the horizontal translation of the lumbar spine marker within a 3 m field of view that encompassed obstacle approach and negotiation for the 2 m prior to and 1 m after the obstacle.

Descriptive statistics were obtained and data screened for outliers. The coefficient of variation was used to compare within-subject FC variability (FCV) between single and dual-task conditions. Paired difference *t*-tests were used to compare all gait parameters and 1-back task performance between single and dual-task conditions. Because the randomized starting locations may have differentially influenced variability of SL, TO and OH, paired difference *t*-tests of the coefficient of variation of these variables were performed across conditions. The significance level for all *t*-tests was set at $P \leq 0.05$. Because of the exploratory nature of the study, the α level was not corrected for multiple comparisons. One-way analysis of variance was conducted on each dependent variable to determine whether order effects existed across multiple trials. SPSS Version 10.0 was used for all statistical analyses (SPSS Inc., Chicago, IL).

3. Results

All subjects completed testing without difficulty. One instance of a subject's lead heel contacting the obstacle was observed, but no gait disruption occurred. Nineteen subjects

Table 2
Mean values, S.D. and ranges for gait parameters under single-task and dual-task conditions

Gait parameter	Single-task		Dual-task		*P*-values
	Mean (S.D.)	Range	Mean (S.D.)	Range	
COPE (m)	0.042 (0.017)	0.021–0.079	0.043 (0.016)	0.027–0.087	n.s.
COPV (m/s)	0.278 (0.051)	0.187–0.379	0.274 (0.047)	0.191–0.364	n.s.
FC (m)	0.114 (0.028)	0.078–0.182	0.114 (0.028)	0.081–0.179	n.s.
FC variability* (%)	13.28 (3.01)	6.74–17.40	12.88 (4.29)	6.72–24.42	n.s.
SL (m)	0.795 (0.093)	0.669–1.136	0.805 (0.102)	0.648–1.171	n.s.
SL variability* (%)	4.37 (1.65)	1.60–7.02	4.22 (1.61)	2.29–7.83	n.s.
TO (m)	0.291 (0.052)	0.205–0.419	0.315 (0.049)	0.219–0.441	$P \leq 0.001$
TO variability* (%)	20.41 (6.68)	11.73–35.02	18.88 (7.24)	8.70–37.80	n.s.
OH (m)	0.188 (0.071)	0.055–0.348	0.173 (0.070)	0.038–0.367	$P \leq 0.009$
OH variability* (%)	26.20 (9.30)	10.60–44.27	26.89 (8.54)	15.35–48.44	n.s.
OGS (m/s)	1.45 (0.249)	0.74–1.84	1.44 (0.263)	0.62–1.81	n.s.
CGS (m/s)	1.48 (0.274)	0.82–2.16	1.48 (0.291)	0.73–2.25	n.s.

* Coefficient of variation.

wore either athletic style walking shoes or flat-heeled casual shoes for testing. One subject wore high heels and another wore sandals with straps. Seventeen of the 21 subjects were instructed to step over the obstacle with their dominant foot after a trial was repeated three times because of stepping with the non-dominant foot.

Table 2 shows the descriptive statistics for each gait variable under single and dual-task conditions. Condition had a significant effect on foot distance from the obstacle. Subjects demonstrated an increased TO ($t = 3.87$; df = 20; $P \leq 0.001$) and a decreased OH ($t = 2.90$; df = 20; $P \leq 0.009$) under dual-task conditions. Under dual-task conditions, subjects placed their trail foot an average of 0.024 m farther from the front edge of the obstacle and their lead heel an average of 0.014 m closer to the rear edge of the obstacle after crossing it. Paired *t*-tests revealed non-significant effects of condition on COPE, COPV, FC, FCV, OGS and CGS ($P > 0.05$). There were no differences between OGS and CGS ($P > 0.05$) under either condition, suggesting that gait speed over the entire walkway and gait speed during obstacle approach and negotiation were not differentially affected by performance of the 1-back task. Additional analysis revealed no differences between single and dual-task conditions in variability of SL, TO or OH ($P > 0.05$). Statistical power for the non-significant gait variables using an effect size of 0.2 ranged from 82 to 99% for all variables except COPE, which was 54%. One-way analysis of variance revealed non-significant order effects for each dependent variable ($P > 0.05$).

During baseline testing of the 1-back task, 18 of the 21 subjects performed the 1-back task at a baseline rate of one number every 1.2 s and the remaining three subjects performed the task at a rate of 2.4 s. Overall, 17 subjects demonstrated a decrement in 1-back task performance under dual-task conditions compared to single-task performance ($t = 2.99$; df = 20; $P \leq 0.007$). The mean percentage correct under the single-task condition was 98.2 vs. 92.7% correct under the dual-task condition. Decreased 1-back task performance was consistent across presentation rates.

Further analysis of individual subject results revealed that one subject, subject 3, exhibited much slower gait speeds than the other subjects for both the OGS and CGS under single and dual-task conditions. This subject's OGS of 0.74 m/s under single-task conditions was > 2 S.D. below the group mean of 1.45 m/s and her OGS of 0.62 m/s under dual-task conditions was > 3 S.D. below the group mean of 1.44 m/s. This subject also exhibited unusually large changes in performance under dual-task conditions as compared to the other subjects. The OGS of subject 3 decreased 0.12 m/s from single to dual-task conditions compared to an increase of 0.01 m/s for the group as a whole. COPE for subject 3 increased 0.012 m from single to dual-task conditions compared to an increase of 0.001 m for the group as a whole. Subject 3 also demonstrated the largest decrement in secondary task performance during dual-task trials compared to the other subjects. Percentage correct for the 1-back task was 100% at baseline and decreased to 69.5% under dual-task conditions.

Observations during testing revealed that some of the subjects delayed their verbal responses to the 1-back task while stepping over the obstacle, responding immediately after clearing the obstacle and just prior to presentation of the next number on the tape as opposed to immediately after the number presentation. Unfortunately, specific instances of response delays were not carefully documented. Another observation during testing was that subjects seemed to take dual-task trials more seriously than single-task trials. One subject commented that he felt as though he had ‘more purpose’ during the dual-task trials.

4. Discussion

Efficient allocation of attentional resources between concurrent tasks is necessary for functional independence involving activities of daily living as well as higher multilevel motor processing tasks. For instance, older adults living independently in the community must be able to engage in conversation while walking, opening a door or preparing a meal without compromising physical performance or stability. Based on the results of the present study, community dwelling older adults appear to be able to walk while performing a complex cognitive task requiring continuous processing without gait changes that may lead to instability or an increased risk of falling.

Older adults in this study modified trail and lead foot positions relative to the obstacle and demonstrated decreased performance of the 1-back task under dual-task conditions. However, COPE, COPV, FC, FCV and SL remained stable when fast walking and stepping over an obstacle were performed with a simultaneous continuous cognitive task.

Subjects in this study positioned their trail foot farther away from the front edge of the obstacle during the dual-task condition. This increased toe-obstacle distance may suggest a gait modification to reduce the risk of foot contact with the obstacle or tripping [27]. Chen et al. [27] suggested this strategy may reduce the risk of tripping by exploiting the ankle dorsiflexion that occurs later in the swing phase of the lead foot. By initiating the crossing step of the lead foot farther away from the obstacle, the foot is further forward in its swing cycle when it crosses the obstacle. An increase in toe-obstacle distance may also represent a more conservative strategy for avoiding contact of the trail foot with the obstacle [28]. Chou et al. [28] reported that in young adults shorter toe-obstacle distances resulted in less hip, knee and ankle flexion, and trail foot vertical toe clearance as obstacles of various heights were crossed. In their study, shorter toe-obstacle distances were also associated with a greater risk of trail foot contact with the obstacle. Subjects in our study appear to have used a stepping strategy during the more challenging dual-task condition that minimized the potential for contact of either foot with the obstacle.

Subjects in this study displayed a decrease in OH distance, consistent with the finding that TO increased, while SL remained unchanged. This gait modification supports the suggestion of Chen et al. [27] that older adults may compromise the distance between the rear edge of the obstacle and the lead heel in order to avoid toe-obstacle contact. Heel contact with an obstacle may pose less risk than toe contact because it is less likely to result in a trip [27]. In both our study and the Chen et al. [27] study, the heel was the lowest point of the foot over the obstacle. The single instance of contact with the obstacle in this study was heel-obstacle contact. The older adults in this study demonstrated an increased TO and thereby a reduced risk of toe contact, but a greater risk of heel contact under dual-task conditions as compared to single task conditions.

While randomizing starting locations may have limited pre-planning of the stepping sequence, it may have also introduced increased variability in SL, TO and OH. Unfortunately, we did not measure variability of these parameters under a constant starting location for comparison. However, there were no differences in the variability of these measures between single and dual-task conditions.

In our study, dual-task performance of the 1-back cognitive task significantly decreased compared to single-task performance. A marked decrement in one or both of the tasks is suggestive of attentional demands exceeding available resources [14]. The ability of subjects to maintain gait speed and conservatively modify foot placement suggests they were able to efficiently allocate attentional resources and prioritize the tasks. Although a significant decrement in secondary task performance occurred, the percentage of correct responses under dual-task conditions was still relatively high (92%), indicating that subjects were attending to both tasks.

Mean values for fast walking speed in this study are consistent with those previously reported for community dwelling older adults [29,30]. The lack of change in gait speed for our subjects during dual-task trials may be explained in several ways. The level of difficulty of the primary and/or secondary tasks may not have been sufficiently challenging to alter gait speed. Low obstacles may be relatively easy for independent, community dwelling older adults to negotiate, even at fast walking speeds. Perhaps a higher obstacle or shorter approach distance would have been more challenging for this population and resulted in greater interference of the concurrent tasks. In addition, the fastest presentation rate of 1.2 s between recitation of numbers on the tape may have been too slow to challenge most of the subjects we tested. Eighteen of the 21 subjects tested were able to achieve 90% accuracy or better at the fastest presentation rate of 1.2 s under single-task conditions. The 1-back task allows for responses to be given anytime during the interval before presentation of the next number. Subjects may have been able to briefly switch their attention to gait when negotiating the obstacle without affecting the accuracy of their performance on the 1-back task.

The rhythmic nature of the secondary task may have influenced gait speed. The fast paced auditory presentation of numbers (one number every 1.2 s) may have had a pacing or an arousal effect for some subjects. Abernethy [31] reported increased arousal may occur under dual-task conditions. Observations and subject comments during testing suggested subjects may have approached dual-task trials more seriously or with ‘more purpose’ than single-task trials and this may have influenced gait speed under dual-task conditions. Another consideration is that subjects may have compromised performance on the cognitive task in favor of maintaining gait speed.

Comparison of gait speed under dual-task conditions to previous findings is difficult because most researchers have attempted to hold gait speed constant in order to make inferences about residual cognitive processing abilities on the basis of changes in secondary task performance. Lundin-Olsson et al. reported slower walking times for the Timed Up and Go Test [32] under dual-task conditions compared with single-task walking times in older adults living in senior apartments and assisted living residences [20,21]. Their results suggest that a frailer population may experience more interference between two tasks and be at increased risk of falls compared to the community dwelling subjects included in our study.

The mean fast walking speed under single-task conditions for subject 3 (an 88-year-old female) in this study was significantly below the normative speeds reported in the literature. The mean maximal gait speed reported by Rantanen and Avela [30] for an 85-year-old women living independently in the community was 1.22 m/s (S.D. = 0.29). OGS and CGS for subject 3 were 0.74 and 0.81 m/s, respectively under single-task conditions. This subject's slow gait speed may have been partially attributable to the high-heeled shoes she chose to wear as 'customary footwear' for testing. Other indicators suggest she may have been frailer compared to the other subjects. She was the oldest subject in the study, was one of two subjects who reported 'occasional' use of a cane to ambulate and was also one of two subjects with the lowest visual contrast sensitivity. The interference between physical and cognitive task performance under dual-task conditions exhibited by subject 3 may be suggestive of a greater potential for performance decrement in frailer older adults. Further investigation of dual-task abilities in frail older adults is needed to determine whether cognitive tasks interfere with walking performance in this population.

Chen et al. [19] reported that dividing attention significantly reduced virtual obstacle avoidance scores in both young and older adults, with older adults showing a greater decrement. Subjects in their study were given 350 or 450 ms to avoid a suddenly appearing obstacle. In the present study, the obstacle was in a constant location and in view for the entire length of the walkway during all trials. Subjects had the opportunity to monitor and alter their approach to the obstacle, rather than modifying their gait suddenly in response to the sudden appearance of an obstacle. Subjects in this study showed consistency of foot clearance between single and dual-task conditions and all were able to successfully step over the obstacle under both conditions. Although maintenance of a fast walking speed while approaching and stepping over an obstacle may have limited generalization to everyday life, this task does provide information regarding older adults' ability to perform a more challenging gait task with a concurrent cognitive task. While both types of obstacle avoidance situations may occur in everyday life, perhaps older adults have greater difficulty with obstacle avoidance when dividing attention under critical time constraints. The risk of tripping may have influenced the priority given to successful obstacle negotiation in our study. Failure to avoid the obstacle in our study could potentially lead to a trip or fall because a real obstacle was used. In the study by Chen et al. [19] subjects may have placed less priority on obstacle avoidance because the obstacle was a light beam projected across the walkway, with no risk of physical disturbance of gait.

Although the 1-back task was a continuous secondary task that could be easily quantified and adjusted in difficulty level for each subject, the nature of the task may have imposed some important limitations on the results of the study. As mentioned previously, the fast paced auditory presentation of numbers may have produced an arousal effect during the dual-task trials. The observed response delay was not reflected in 1-back task scores because verbal response speed was not measured. Although no differences were observed for OGS versus CGS under either condition, understanding of whether performance around the obstacle was differentially affected by the 1-back task is limited by the lack of a measure of verbal response time for the 1-back task and additional gait parameters, such as center of mass motion. Subjects may have switched attention from the cognitive to the gait task at the critical time of obstacle negotiation. The relative importance of the secondary task to the subjects may also have influenced their prioritization of the tasks. Recalling numbers may be perceived as less important than more personal tasks, such as speaking with a friend or answering the telephone. Consequently, maintaining performance of the 1-back task may have received less priority for attentional resources than a secondary task of more personal importance.

The auditory nature of the 1-back task may have also limited potential interference with the gait task. Encoding, maintenance and recitation of auditory information are theorized to occur through the actions of the phonophologic loop of working memory [33]. Maylor and Wing [16] reported a significant decrease in standing balance during concurrent performance of tasks requiring use of the visuo-spatial sketchpad component of working memory compared to tasks utilizing the phonophologic loop. The authors suggested concurrent processing of visuo-spatial information might limit the use of external visual information for balance.

The older adults in this study were able to adjust their gait while approaching the obstacle under both conditions, as demonstrated by successful obstacle avoidance. Unfortunately, we were unable to ascertain how far from the obstacle adjustments may have been made due to room constraints that prevented us from utilizing a larger field of view. The field of view only allowed measurement of the 2-m or one to two steps, prior to crossing the obstacle. Because no changes occurred in CGS or SL within the field of view we can assume if modifications of these variables were made, they occurred farther away from the obstacle. Inclusion of additional variables, such as center of mass displacement or movement efficiency, may have provided information about other modifications that were made and should be considered in future investigations.

The dual-task paradigm has inherent limitations with regard to subjects' prioritization of tasks. Although we instructed subjects to emphasize performance of both tasks, it is not possible to ascertain with certainty if subjects prioritized one task over the other. It is possible that some subjects prioritized gait, while other prioritized the cognitive task. Subjects may have made an extra effort to clear the obstacle compared to stepping over an obstacle in the community. Extraneous noises and information were minimized in order for the subjects to hear the audiotape and perform the tasks. The reduction of irrelevant stimuli may have limited the application of the results to the more distracting environments, typically encountered in everyday life. In addition, most of these subjects were high functioning, thus limiting generalization to community-dwelling older adults who have mobility or cognitive deficits.

5. Conclusion

Results of this study indicate that independent, community dwelling older adults experience interference with performance of concurrent gait and cognitive tasks, but are able to adequately allocate attentional resources to conservatively modify or preserve gait performance as measured by these gait parameters. Subjects modified foot placement relative to the obstacle in ways associated with reduced risk of foot contact with the obstacle. Use of this conservative strategy and preservation of gait speed, foot clearance and stability, in combination with a small decrement in secondary task performance suggests that subjects may have placed a higher priority on maintaining gait performance during dual-task conditions. Allocation of attentional resources in favor of maintaining stability and obstacle avoidance is necessary to preserve functional independence in older adults. While our subjects were able to allocate attentional resources successfully during these concurrent tasks, further research is needed to investigate dual-task abilities of older adults in community environments and of frailer older adult populations.

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