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Research Article

Dual-Task Gait Assessment in a Clinical Sample: Implications for Improved Detection of Mild Cognitive Impairment

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Abstract

Objectives: Research has longitudinally linked dual-task gait dysfunction to mild cognitive impairment (MCI) and dementia risk. Our group previously demonstrated that dual-task gait speed assessment distinguished between subjective cognitive complaints (SCC) and MCI in a memory clinic setting, and also found that differences in dual-task gait speed were largely attributable to executive attention processes. This study aimed to reproduce these findings in a larger diverse sample and to extend them by examining whether there were group differences in single- versus dual-task cognitive performance (number of letters correctly sequenced backward).

Method: Two-hundred fifty-two patients (*M* age = 66.01 years, *SD* = 10.46; 119 MCI, 133 SCC) presenting with cognitive complaints in an academic medical setting underwent comprehensive neuropsychological and gait assessment (single- and dual-task conditions).

Results: Patients with MCI walked slower and showed greater decrement in cognitive performance than those with SCC during dual-task conditions. Neuropsychological measures of executive attention accounted for significant variance in dual-task gait performance across diagnostic groups beyond demographic and health risk factors.

Discussion: Reproduction of our results within a sample over four times the previous size provides support for the use of dual-task gait assessment as a marker of MCI risk in clinical settings.

Keywords: Cognition, Dementia, Executive, Preclinical, Walking

Alzheimer's disease (AD) and other dementias are a significant health problem facing today's society. Approximately 14% of American adults older than 70 years develop dementia (Plassman et al., 2007), with approximately one third of adults aged 85 years and older afflicted by AD specifically (Alzheimer's Association, 2017). There is an even larger number of adults with mild cognitive impairment (MCI), often recognized as the prodromal stage of dementia. In light of the burgeoning older adult population and high prevalence of dementias, it is critical to identify early markers of dementia risk. Research efforts are increasingly focused on MCI or even earlier preclinical stages for detection and intervention.

Clinical diagnosis with neuropsychological assessment combined with neurological evaluation remains the gold standard for differential diagnosis of neurocognitive impairment, but these methods are often time intensive and costly. There is a need for a simple, easily measurable clinical marker for risk of MCI, to help identify individuals who would benefit from further assessment. Dual-task gait assessment may serve as a particularly useful screening measure of MCI risk in clinical settings.

It is increasingly recognized that there are early changes in gait among individuals who develop dementia. Among healthy older adults, studies have shown decreases in overall gait speed and increased gait variability (e.g., Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Hollman, Kovash, Kubik, & Linbo, 2007; Hollman, McDade, & Petersen, 2011a). These gait changes become more pronounced among older adults with cognitive impairment (Allali et al., 2008; Verghese et al., 2002; Waite et al., 2005). As such, gait dysfunction under single-task conditions has been linked to the eventual development of cognitive decline and dementia (Mielke et al., 2013; Verghese et al., 2002; Verghese, Holtzer, Lipton, & Wang, 2009; Verghese, Wang, Lipton, Holtzer, & Xue 2007).

Researchers are increasingly investigating gait in more challenging dual-task conditions (i.e., with an added cognitive load), in which the ability to complete both tasks simultaneously depends on effective allocation of cognitive resources. For example, spelling a word backward has been noted to test working memory and concentration abilities (Lezak, Howieson, & Loring, 2004) and has been shown to evoke a dual-task-related gait disturbance in several studies of normal aging adults (Hollman et al., 2007, 2011b; MacAulay, Brouillette, Foil, Bruce-Keller, & Keller, 2014; MacAulay et al., 2015, 2016) and in MCI (MacAulay Wagner, Szeles, & Milano, 2017), with evidence supporting that executive function and attention/processing speed underlie these relationships. Gait is understood to activate both subcortical motor and higher-level cognitive functions (Yogev-Seligmann, Hausdorff, & Giladi, 2008). Brain regions associated with gait speed in older adults include the motor, supplementary motor, fusiform, precuneus, cerebellum, and prefrontal cortex (especially ventrolateral prefrontal) regions (Blumen et al., 2019; Rosano, Aizenstein, Studenski, & Newman, 2007a; Rosano et al., 2008). Dual-task gait speed in older adults has been linked to the medial and superior frontal gyri, anterior cingulate, cingulate, precuneus, fusiform gyrus, middle occipital gyrus, and inferior and middle temporal gyri (Doi et al., 2017).

Research has suggested that dual-task gait dysfunction is linked to age (Beauchet et al., 2003; Dubost et al., 2006; Ebersbach, Dimitrijevic, & Poewe, 1995; Hawkes, Siu, Silsupadol, & Woollacott, 2012), complexity of the dual-task demands (Muir et al., 2012), and medical comorbidities, including diabetes (Arvanitakis et al., 2004; Brach, Talkowski, Strotmeyer, & Newman, 2008), thyroid dysfunction (Bano et al., 2016), cerebrovascular disease (Verghese et al., 2002), cardiovascular disease (Matsuzawa et al., 2013), dyslipidemia (Okoro et al., 2006), and hypertension (Rosano et al., 2011). Neuroanatomically, studies have found associations between subclinical vascular abnormalities on brain scans (e.g., hyperintensities, infarcts) and increased gait dysfunction (Rosano, Brach, Studenski, Longstreth, & Newman, 2007b; Whitman, Tang, Lin, Baloh, & Tang, 2001). Overall, the evidence to date suggests that gait is affected by the presence of cognitive impairment, age, presence and difficulty of dual tasks, and medical comorbidities. Whether these findings extend to dual-task gait characteristics is uncertain (MacAulay et al., 2017).

Data-intensive gait analyses in older adult populations have been conducted in laboratory settings using sophisticated technological systems (e.g., GAITRite system) to measure numerous gait parameters. This enables fine-grained analysis of gait, but may or may not generalize to clinical settings and samples. A growing body of research has confirmed that dual-task gait parameters can distinguish between normal aging and MCI and are associated with progression to dementia (e.g., Klotzbier & Schott, 2017; Montero-Odasso et al., 2014, 2017; Muir et al., 2012). Yet a dearth of research has examined gait in clinical treatment-seeking samples as opposed to research samples. To the best of our knowledge, existing studies demonstrating dual-task gait differences between normal aging and MCI participants have used community volunteers to comprise the cognitively normal control group. Older adult research volunteers typically are not representative of the population (e.g., healthier, more educated; Welsh-Bohmer et al., 2009), which may emphasize group differences in gait. It is important to analyze whether results of research studies extend to clinical settings. Of note, patients evaluated in clinical settings typically present with some degree of subjective cognitive concerns; therefore, the key question is whether dual-task gait assessment can differentiate between subjective cognitive complaints (SCC; i.e., subjective cognitive concerns but performance within normal limits on objective neuropsychological examination) and MCI.

To the best of our knowledge, our group was the first to examine this important question in individuals presenting with cognitive complaints to a memory clinic (MacAulay et al., 2017). Findings from this study indicated that differences in dual-task gait speed appear to be largely attributable to executive attention processes, as measured by neuropsychological tests. This study, in line with other similar investigations (e.g., Holtzer, Verghese, Xue, & Lipton, 2006; Holtzer, Wang, & Verghese, 2012; MacAulay et al., 2014), specifically inspected neuropsychological tests of complex visual attention, visuomotor/spatial integration, divided attention/set-shifting, and psychomotor speed as different aspects of the construct of executive attention. In contrast to the significant contribution of executive attention processes to dual-task gait speed, the presence of medical risk factors as measured by clinical history was not predictive of gait speed in either task condition. This study sought to reproduce this investigation in a larger, diverse sample and to extend these findings by examining whether there were group differences in cognitive performance during the single- versus dual-task condition. It was expected that the MCI group would demonstrate slower dual-task gait speed (i.e., take longer to walk with a dual-task cognitive load) relative to the SCC group, and that this difference would be largely attributable to neuropsychological measures of executive attention. It was additionally expected that the MCI group would demonstrate poorer cognitive performance (i.e., fewer letters correctly sequenced backward) during the dual-task condition compared to the SCC group.

Method

Participants

The sample consisted of patients presenting with cognitive concerns to an outpatient neuropsychology clinic in an academic medical setting between November 2015 and June 2017. The study design consisted of retrospective chart review analysis of data routinely collected as part of patients' standard clinical neuropsychological evaluations. This study was approved by the Medical University of South Carolina Institutional Review Board, and all human data were obtained in compliance with institutional regulations. As this was translational research, we were interested in a representative clinical population across a broad age range of middle-to-older-aged adults. Thus, inclusion criteria were intentionally set to be wide. Exclusion criteria included age less than 45 years, intellectual disorders, moderate-to-severe cognitive impairments (defined as Mini-Mental State Examination [MMSE] scores ≤18; Folstein, Folstein, & McHugh, 1975), clinical diagnosis of dementia, probable normal pressure hydrocephalus, and recent major strokes (i.e., within the past year). Participants were also excluded based on clinical judgment regarding patient's inability to safely ambulate independently (e.g., balance problems determined from medical history [such as history of multiple falls], observation, reliance on an assistive device for ambulation, and/or patient report).

The final sample consisted of 252 patients (145 female, 107 male) with a mean age of 66.01 years (*SD* = 10.46 years). Sixty-one of these patients were part of a prior study (MacAulay et al., 2017). Mean education level for the current sample was 14.73 years (*SD* = 2.75). Patients were predominantly Caucasian (*n* = 221, 87.70%). Retrospective chart review included extraction of recorded clinical diagnoses of either SCC or MCI; these diagnoses had been made based on performance on neuropsychological testing, medical chart review, and clinical interview with patient and collateral informant (when available). Petersen (2004) criteria were used for MCI diagnosis. SCC was applied to patients who presented with self-reported cognitive complaints but who did not meet criteria for MCI.

All final diagnostic decisions were made by a licensed clinical neuropsychologist. On the basis of these diagnostic classifications, 133 (52.80%) were diagnosed with SCC and 119 patients (47.20%) were diagnosed with MCI. Information regarding clinical subtypes of MCI (e.g., amnestic vs non-amnestic) was unavailable through retrospective chart review. However, the most common suspected etiologies for MCI were recorded as mixed (*n* = 52), cerebrovascular disease (*n* = 39), and probable AD (*n* = 20) based on a chart review of available medical records according to standard clinical care procedures.

Clinical Assessment

All patients received clinical standard of care procedures with a licensed clinical neuropsychologist, clinical neuropsychology postdoctoral fellow, and/or clinical psychology intern in an outpatient neuropsychology clinic. All patients were referred for evaluation of SCC. On the basis of results of clinical interview (as documented in each patient's neuropsychological evaluation report) and medical chart review, presence of various medical/health variables was recorded, including hypertension, hyperlipidemia, diabetes, thyroid disorder, history of major cerebrovascular event occurring more than 1 year prior to the evaluation, and/or history of major cardiovascular (e.g., myocardial infarction) event. For this study, these variables were dichotomously coded to indicate presence or absence of the health risk factor.

All patients underwent comprehensive neuropsychological testing as part of their evaluation using a fixed-flexible battery; thus, not all patients completed the same measures. Patients were evaluated across multiple cognitive domains, including verbal and nonverbal memory, attention/psychomotor speed, language, visuospatial, and executive functions. Consistent with prior work inspecting the construct of executive attention as it relates to gait (Holtzeret al., 2006; Holtzeret al., 2012; MacAulay et al., 2014), key neuropsychological measures of executive attention were analyzed for this study, including Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) Block Design and Digit Symbol Coding subtests and Trail Making Test (TMT A and B, time in seconds). Executive attention test scores were converted to *z* scores based on the study sample prior to statistical analyses.

Patients also completed the MMSE (Folstein, Folstein, & McHugh, 1975) early in the evaluation prior to gait assessment. The MMSE includes spelling the word "world" backward; the number of correctly sequenced letters was recorded for this single-task/non-walking condition to serve as a reference for performance when asked to spell the same word ("world") backward during a dual-task condition (i.e., walking while spelling the word backward). Patients were seated while performing this single-task/MMSE item of spelling "world" backward. Per standard clinical procedures for MMSE administration, patients performed this task once, were not provided with a time limit for completing the task, and were not provided with feedback about their performance.

Gait Assessment

After completing neuropsychological testing, all patients completed standardized gait assessment procedures. Gait assessment was done in an adjacent hospital hallway, 23 feet long. Patients had four-foot acceleration and deceleration phases for each trial, so the length of hallway used for the measured gait assessment was 15 feet long (4.572 m). For all trials, patients were instructed to walk across the hallway using their "normal, everyday walking speed." Time to complete each trial was collected via a stopwatch and recorded in seconds to the 100th place. Examiners walked behind patients out of their field of vision to decrease distractions and prevent patients from adjusting their gait speed to match the examiner. In addition, examiners made every effort to have patients complete the gait assessment at times when there were minimal external distractions present in the environment (e.g., noises, non-study personnel walking past the hallway); however, given the proximity of the hospital hallway to the clinic setting, it was impossible to entirely eliminate all possible distractions.

Four gait trials total were administered to each patient. The first two trials consisted of a single-task, walking-only measurement to gather baseline gait speed in the absence of cognitive load. The second set of two trials assessed gait speed under a cognitive load dual-task condition. Gait disturbances and decreased cognitive efficiency related to walking and performing a cognitive task are widely believed to reflect competing demands for attentional resources that are affected by executive dysfunction (see Sheridan & Hausdorff, 2007). The cognitive task of spelling five-letter words backward was thus selected based on the widely held validity of the MMSE subtest of spelling "world" backward serving as a sensitive measure of concentration and working memory that are not reliant on mathematical abilities (Folstein, Folstein, & McHugh, 1975; Lezak et al., 2004; Hollman et al., 2011b). Indeed, previous studies have demonstrated that the use of spelling a five-letter word backward as a cognitive dual task can reliably provoke a dual-task gait cost in older adults with and without cognitive concerns (Hollman et al., 2007, 2011b; MacAulay et al., 2014, 2015, & 2017). In this study, patients were instructed to spell a five-letter word aloud as they walked across the hallway. Patients were asked to spell "world" backward in Trial 1 and "arrow" backward in Trial 2. This procedure is consistent with prior dual-task gait assessment research (e.g., Hollman et al., 2007; MacAulay et al., 2014, 2015). Average time of completion (in seconds to the 100th place) were calculated for the two single-task trials and the two dual-task trials; that is, one score for single-task gait speed and one score for dual-task gait speed were produced for each patient, based on their average score across the two trials under each condition. In addition to gait speed, cognitive performance during dual-task gait trials (i.e., the number of correctly sequenced letters) was recorded; for this study, cognitive performance when spelling "world" backward under the dual-task condition was of particular interest as patients were also asked to spell this same word backward under a single-task (i.e., MMSE) condition earlier in their neuropsychological evaluation.

Statistical Analyses

All statistical analyses were conducted in IBM SPSS v. 23. Level of statistical significance was set at p value of less than .05 for all analyses. Descriptive statistics and frequencies were generated to characterize demographic information for the full sample. Correlations were used to analyze demographic influences on gait for the full sample. Additional preliminary analyses analyzed group differences in demographic and clinical variables via t tests and chi-square analyses.

A repeated-measures analysis of variance (ANOVA) was conducted to examine between-group differences in single- and dual-task gait. Gait speed (i.e., average time of completion for each gait condition) was entered as the dependent variable with two levels (single- and dual-task conditions). As noted earlier, one score for single-task gait speed (averaged across the two trials administered) and one score for dual-task gait speed (averaged across the two trials administered) were entered into the model. Cognitive status (SCC vs MCI) was entered as the between-subjects factor. Age and sex were entered into the model as covariates. Because age differences in gait time and cognitive status were expected, age was first standardized by cognitive status group.

To examine how well dual-task gait performance can distinguish between SCC and MCI groups, a receiving operating characteristic (ROC) curve was produced, which allows for inspection of classification performance at various threshold settings. The area under the curve (AUC) was the primary outcome of interest; values range from .5 to 1.0, with higher values indicating better ability to distinguish between the two groups based on dual-task gait performance.

Effects of dual-task on cognitive efficiency (i.e., the number of correctly sequenced letters when spelling "world" backward) between diagnostic groups were also analyzed. A repeated-measures ANOVA analyzed a potential interaction between task condition (single-task/MMSE vs dual-task gait) and cognitive status (SCC vs MCI). Again, age and sex were entered into the model as covariates.

Hierarchical regressions were conducted to examine influences of demographic and health variables, executive attention, and cognitive status on gait time within single- and dual-task conditions. Single- and dual-task gait time were entered as the dependent variables in separate models. Four blocks of independent variables were entered for each regression model. Demographic variables (age, sex, education) were entered in the first block, followed by health variables (hypertension, hyperlipidemia, diabetes, cardiovascular event, cerebrovascular event, thyroid disorder). The third block was composed of executive attention measures (Block Design, Digit Symbol Coding, TMT A, TMT

B). The last block was cognitive status (SCC vs MCI). *R*-squared, adjusted *R*-squared, changes in *R*-squared and *F*, and standardized coefficients for the final regression models were analyzed to examine respective contributions to gait dysfunction for each of these variables.

Results

Table 1 presents descriptive statistics for demographic and clinical factors for the SCC and MCI groups. As expected, the MCI group was significantly older and had lower MMSE and executive attention test scores than the SCC group. In addition, the SCC group was composed of a greater proportion of women than was the MCI group. Educational attainment was not significantly different between the two groups. Relative to those with SCC, a greater proportion of the MCI group had significant health risk factors, including hyperlipidemia, hypertension, and history of cerebrovascular and cardiovascular events. There were no between-group differences for diabetes or thyroid disease.

Differences in Gait Between SCC and MCI

Repeated-measures ANOVA revealed a significant interaction between task condition and diagnostic group on gait time, indicating that the MCI group had a greater dual-task decrement in gait speed than the SCC group ($F(1, 214) = 12.66$, $p < .001$, partial $\eta^2 = .06$; see Figure 1); that is, relative to their baseline walking speed, the MCI group slowed down more significantly with the added cognitive load of the dual-task condition than did the SCC group. There was a significant main effect between task conditions, indicating that average gait time was significantly longer during the dual-task relative to the single-task walking condition across all patients ($F(1, 214) = 19.90$, $p < .001$, partial $\eta^2 = .09$). There was also a significant between-group main effect, showing that the MCI group overall walked significantly slower than did the SCC group ($F(1, 214) = 18.30$, $p < .001$, partial $\eta^2 = .08$); however, post hoc analyses with Bonferroni correction revealed that the MCI group walked significantly more slowly than the SCC group under dual-task but not single-task conditions.

A ROC curve was produced to allow for inspection of how well dual-task gait performance could distinguish between SCC and MCI groups at various threshold settings. The produced AUC value was .63, which was statistically significantly different from a chance-level value of .5; however, it is also acknowledged that this value is on the lower side, as a value of 1.0 represents perfect discrimination. This ROC result suggests that although dual-task gait

Table 1. Demographic and Clinical Characteristics by Cognitive Status

	Total		SCC		MCI		
	n = 252		*n* = 133		*n* = 119		*p*
Age (years)	66.01 (10.46)		62.29 (9.60)		70.16 (9.83)		.001
Education (years)	14.73 (2.75)		14.97 (2.57)		14.45 (2.92)		.14
MMSE (raw)	27.10 (2.52)		28.35 (1.78)		25.72 (2.51)		.001
% female	57.5		64.7		49.6		.02
Single-task gait time (s)	7.16 (1.76)		6.85 (1.46)		7.54 (2.02)		<.01
Dual-task gait time (s)	8.71 (2.64)		8.06 (1.84)		9.59 (3.26)		<.001
Single-task gait speed (m/s)	0.67 (.14)		0.70 (.14)		0.64 (.14)		<.01
Dual-task gait speed (m/s)	0.57 (.15)		0.60 (.14)		0.52 (.15)		<.001
Health risk variables (% present within group)							
Diabetes	18.7		19.5		17.6		.70
Hyperlipidemia	54.8		45.9		64.7		.01
Hypertension	54.4		43.6		66.9		.001
Cardiovascular	13.1		7.5		19.3		.01
Cerebrovascular	17.9		13.1		23.9		.03
Thyroid disorder	25.8		24.2		27.7		.53
Executive attention tests	*n*	*M* (*SD*)	*n*	*M* (*SD*)	*n*	*M* (*SD*)	*p*
Block Design (raw)	186	27.40 (11.92)	102	32.02 (11.50)	84	21.79 (9.89)	<.001
Digit Symbol Coding (raw)	151	46.08 (16.95)	85	52.12 (16.03)	66	38.30 (14.89)	<.001
TMT Part A (s)	227	49.93 (29.56)	126	41.03 (19.24)	101	61.03 (35.89)	<.001
TMT Part B (s)	229	143.38 (103.08)	126	103.13 (70.21)	103	192.61 (115.15)	<.001

Note: Above statistics depict mean (standard deviation) for each variable unless otherwise specified. SCC = subjective cognitive complaints; MCI = mild cognitive impairment; MMSE = Mini-Mental State Examination; TMT = Trail Making Test. Single-task gait statistics (m/s) represents the average of the two walking-only conditions. Dual-task gait statistics (m/s) represents the average of the two dual-task (walking + cognitive load) conditions. Raw scores are shown for Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) Block Design and Digit Symbol Coding subtests. Owing to the fact that not all participants completed the same neuropsychological battery as part of their clinical evaluation, sample sizes for executive attention tests vary and are presented in the table. *p* values indicate statistical significance of chi-square and *t* tests conducted to examine differences between SCC and MCI groups for each variable.

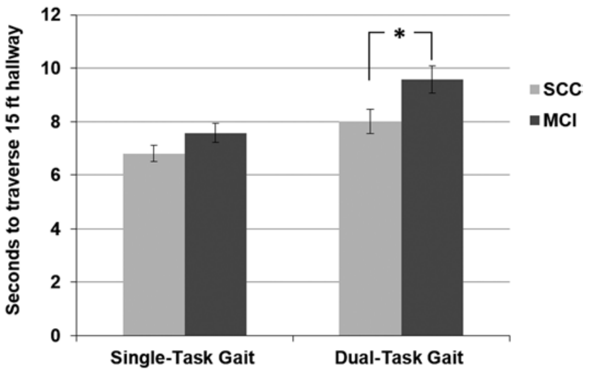

Figure 1. Group × Task Condition interaction for gait speed. Single-task gait is the average time (in seconds) of the two walking-only conditions. Dual-task gait is the average time (in seconds) of the two dual-task (walking + cognitive load) conditions. Analyses controlled for age and sex. Error bars indicate 95% confidence intervals. SCC = subjective cognitive complaints; MCI = mild cognitive impairment. *$p < .001$.

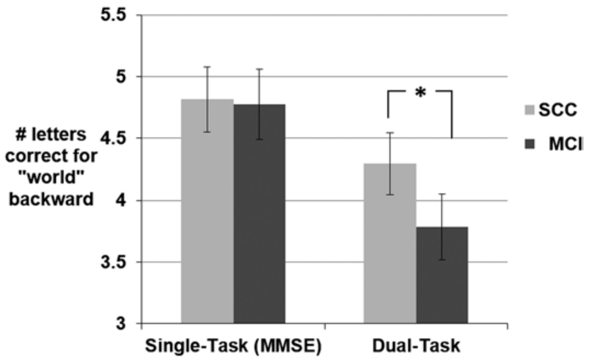

Figure 2. Group × Task Condition interaction for cognitive performance when spelling "world" backward. Analyses controlled for age and sex. Error bars indicate 95% confidence intervals. SCC = subjective cognitive complaints. MCI = mild cognitive impairment. MMSE = Mini-Mental State Examination. *$p = .06$.

performance was significantly different between the MCI and SCC groups, it did not perfectly distinguish between groups in this study, as there was considerable overlap between groups in their dual-task gait time.

Patients with MCI also showed a trend-level decrease in performance for spelling "world" backward under the dual-task condition relative to the single-task/MMSE condition than did patients with SCC (see Figure 2), as indicated by a marginally significant within-subjects interaction between diagnostic group (SCC vs MCI) and task condition (single-task/MMSE vs dual-task) for cognitive performance ($F(1, 237) = 3.52$, $p = .06$, partial $\eta^2 = .02$).

Predictors of Single- and Dual-Task Gait Speed

Hierarchical regressions examined the independent contributions of key variables to both single- and dual-task gait time (see Table 2). For dual-task gait time, demographics and health risk variables each accounted for a nonsignificant proportion of variance. There was a significant change in R^2 with the addition of executive attention measures to the model, which accounted for 25.5% of the variance. There was a nonsignificant change in R^2 when cognitive status was entered. For single-task gait time, demographic variables were a significant predictor and accounted for 7.1% of the variance. The addition of health risk variables resulted in nonsignificant R^2 change. When executive attention measures were added to the model, they accounted for a significant 14.5% of the variance, p value of less than .001. There was a nonsignificant change in R^2 with the addition of cognitive status.

Discussion

Our results provide support for dual-task gait dysfunction as a behavioral marker of MCI and demonstrate that it can be easily implemented within a busy, routine clinical setting. These results reproduced our previous findings (MacAulay et al., 2017) and replicated others' findings (Klotzbier & Schott, 2017; Montero-Odasso et al., 2014; Muir et al., 2012) that gait speed while performing a cognitive task is significantly different between patients with MCI and those with SCC, whereas these diagnostic groups do not differ in simple gait performance. Implications of these findings are now discussed.

Under a cognitive load dual-task condition, the MCI group exhibited a significantly greater decrement in gait speed and cognitive performance than the SCC group even after adjusting for demographic factors. Although the difference in dual-task gait speed between SCC and MCI groups was small, this lines up with other studies that suggest that similarly small changes have been linked to increased risk of dementia (e.g., Bohannon & Glenney, 2014; Dumurgier et al., 2017). It is also likely that this difference in dual-task gait speed between MCI and SCC groups would be even more pronounced given a longer walkway than was used in this study. Refinement of methodology used for dual-task gait assessment (e.g., increasing difficulty of the cognitive load) may be helpful in producing a larger AUC value for improved discrimination between SCC and MCI groups at various threshold thresholds.

It is not surprising that the higher cognitive demand of dual-task conditions elicits cognitive inefficiency in a way that a brief screening instrument like the MMSE cannot. Future work may incorporate additional methods of measuring cognitive inefficiency, such as response time needed to spell a word backward during a dual-task condition. Similarly, for those participants who are able to spell a word backward more quickly, it may be helpful for future investigations to consider complementary or alternative methods to ensure uniform application of the cognitive load across the entire duration of the gait assessment. Our findings also suggest an attenuated practice effect for the MCI group relative to the SCC group when asked to spell "world" backward in single-task (i.e., MMSE) then dual-task conditions,

Table 2. Hierarchical Regression Model Summary for Dual-Task and Single-Task Gait Speed

	R^2	Adj. R^2	*SE*	ΔR^2	ΔF	*p*
Dual-task gait speed						
Model 1: demographics[a]	.04	.02	2.59	.04	2.08	.11
Model 2: Model 1+ health risk variables[b]	.09	.03	2.58	.05	1.14	.34
Model 3: Model 2 + executive attention[c]	.35	.28	2.22	.26	12.22	.00
Model 4: Model 3 + cognitive status[d]	.35	.27	2.23	.00	0.02	.89
Single-task gait speed						
Model 1: demographics[a]	.07	.05	1.70	.07	3.54	.02
Model 2: Model 1+ health risk variables[b]	.13	.08	1.67	.06	1.60	.15
Model 3: Model 2 + executive attention[c]	.28	.21	1.55	.15	6.48	.00
Model 4: Model 3 + cognitive status[d]	.28	.20	1.56	.00	0.16	.69

Note: [a]Demographics: Age, sex, education.
[b]Health risk variables: Diabetes, hyperlipidemia, hypertension, cardiovascular, cerebrovascular, thyroid disorder. These variables were dichotomously coded to indicate presence or absence of each condition.
[c]Executive attention: Block Design, Digit Symbol Coding, Trail Making Test Part A, Trail Making Test Part B. All tests were converted to *z* scores prior to analyses.
[d]Cognitive status: Subjective cognitive complaints vs mild cognitive impairment.

similar to other research studies indicating smaller or absent practice effects among older adults with MCI and dementia (Hassenstab et al., 2015; Machulda et al., 2013). These findings conducted in a large, clinically diverse patient sample increase our confidence in the utility of dual-task gait assessment in clinical settings to help distinguish SCC from MCI.

Executive attention accounted for a significant amount of dual-task gait dysfunction, beyond what was accounted for by influences of age, sex, and education. These findings are also in line with previous results (MacAulay et al., 2017) and suggest that complex visual attention, visuomotor/spatial integration, divided attention/set-shifting, and psychomotor speed are critically important in dual-task gait control. The unique neuropsychological profile of patients with MCI may contribute to the degree of gait dysfunction; that is, MCI patients with more prominent executive attention deficits may have greater impairment in gait speed relative to MCI patients with less severe executive dysfunction. This will be an important area for continued investigation.

Interestingly, dual-task gait dysfunction was unrelated to medical comorbidities in the current sample. This reproduces our prior work yet contrasts with prior work demonstrating adverse influences of cardiovascular disease, diabetes, thyroid dysfunction, and other medical comorbidities on gait (e.g., Arvanitakis et al., 2004; Bano et al., 2016; Matsuzawa et al., 2013; Okoro et al., 2006; Rosano et al., 2011). It is possible that these medical comorbidities may emerge as important influences on gait for specific diagnostic groups, such as those at risk for vascular dementia, but not for other diagnostic groups, such as those in the preclinical stages of AD. It also possible that dichotomized medical characteristics may not capture the complex relationship between physiological aspects of metabolic/vascular function, multitasking performance, and gait (Rucker et al., 2017). Although this study was unable to examine these health risk factors in a more detailed fashion, this will be important for future studies.

This study examined a clinically heterogeneous sample, including patients with MCI due to a variety of etiologies (e.g., AD and vascular); because of this heterogeneity, the modifying influences of these medical comorbidities may have been suppressed. In addition, the majority of patients presented with clinical histories suggestive of multiple etiologies of cognitive dysfunction; thus, this study could not examine differences in gait dysfunction within those with "pure" amnestic or vascular MCI subtypes due to insufficient sample sizes within these groups. Further, information regarding specific clinical subtypes of MCI (e.g., amnestic vs non-amnestic) was unfortunately unavailable in this study, but will be important to incorporate into future work. This study also did not examine small-vessel vascular disease or markers of subclinical vascular abnormalities, but this is an avenue we intend to investigate given evidence of greater subclinical vascular abnormalities on neuroimaging among older adults with gait dysfunction (Rosano et al., 2007b; Whitman et al., 2001). Future research that better characterizes the relationship between medical comorbidities and gait dysfunction (e.g., through the use of biomarkers), including at the level of specific MCI subtypes is needed.

Additional limitations should be noted. This study was unable to control for a variety of factors that may be affecting gait, including neuropathy, weakness, prosthesis, osteoarthritis, or medication effects. Including these variables in future investigations will be important. In addition, the fixed order of the gait trials (i.e., two single-task gait trials followed by two dual-task gait trials) may have served as a limitation, particularly if individuals with MCI fatigue more easily than those with SCC. A counterbalanced order should be considered for future investigations. Given that we used a clinical sample consisting of patients being evaluated for cognitive concerns, we were unable to compare with a strict control group; this is seen as both a strength given the generalizability to clinical settings, as well as a potential limitation. Manual measurement of time to complete each gait trial was used, which may result in a certain degree of imprecision due to human error. Of note, the repeated-measures design used in this study used participants as their own baseline, so any potential effects on gait (e.g., from neuropathy or medication effects) would be present in the single-task gait condition and thus were not expected to affect the dual-task decrement. Nonetheless, measuring and controlling these variables in future studies will be an important avenue to enable cleaner interpretation of the results.

This study provided further support that dual-task gait dysfunction and errors in cognitive performance during walking may be linked to MCI risk in a large, clinically heterogeneous sample of patients seeking clinical care for cognitive concerns. Assessment of gait abnormalities in clinical settings, such as primary care and memory clinics, may be used as a quick, easily implementable, clinical marker of neurocognitive impairment risk to identify individuals warranting further in-depth assessment.

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Conflict of Interest

None reported.

References

Allali, G., Assal, F., Kressig, R. W., Dubost, V., Herrmann, F. R., & Beauchet, O. (2008). Impact of impaired executive function on gait stability. *Dementia and Geriatric Cognitive Disorders*, **26**, 364–369. doi:10.1159/000162358

Alzheimer's Association. (2017). 2017 Alzheimer's disease facts and figures. *Alzheimer's and Dementia*, **13**, 325–373, doi:10.1016/j.jalz.2017.02.001

Arvanitakis, Z., Wilson, R. S., Schneider, J. A., Bienias, J. L., Evans, D. A., & Bennett, D. A. (2004). Diabetes mellitus and progression of rigidity and gait disturbance in older persons. *Neurology*, **63**, 996–1001. doi:10.1212/01.wnl.0000138432.16676.4b

Bano, A., Chaker, L., Darweesh, S. K., Korevaar, T. I., Mattace-Raso, F. U., Dehghan, A., …. Peeters, R. P. (2016). Gait patterns associated with thyroid function: The Rotterdam Study. *Scientific Reports*, **6**, 38912. doi:10.1038/srep38912

Beauchet, O., Kressig, R. W., Najafi, B., Aminian, K., Dubost, V., & Mourey, F. (2003). Age-related decline of gait control under a dual-task condition. *Journal of the American Geriatrics Society*, **51**, 1187–1188. doi:10.1046/j.1532-5415.2003.51385.x

Blumen, H. M., Brown, L. L., Habeck, C., Allali, G., Ayers, E., Beauchet, O., …. Verghese, J. (2019). Gray matter volume covariance patterns associated with gait speed in older adults: A multi-cohort MRI study. *Brain Imaging and Behavior*, **13**, 446–460. doi:10.1007/s11682-018-9871-7

Bohannon, R. W., & Glenney, S. S. (2014). Minimal clinically important difference for change in comfortable gait speed of adults with pathology: A systematic review. *Journal of Evaluation in Clinical Practice*, **20**, 295–300. doi:10.1111/jep.12158

Brach, J. S., Talkowski, J. B., Strotmeyer, E. S., & Newman, A. B. (2008). Diabetes mellitus and gait dysfunction: Possible explanatory factors. *Physical Therapy*, **88**, 1365–1374. doi:10.2522/ptj.20080016

Doi, T., Blumen, H. M., Verghese, J., Shimada, H., Makizako, H., Tsutsumimoto, K., …. Suzuki, T. (2017). Gray matter volume and dual-task gait performance in mild cognitive impairment. *Brain Imaging and Behavior*, **11**, 887–898, doi:10.1007/s11682-016-9562-1

Dubost, V., Kressig, R. W., Gonthier, R., Herrmann, F. R., Aminian, K., Najafi, B., & Beauchet, O. (2006). Relationships between dual-task related changes in stride velocity and stride time variability in healthy older adults. *Human Movement Science*, **25**, 372–382. doi:10.1016/j.humov.2006.03.004

Dumurgier, J., Artaud, F., Touraine, C., Rouaud, O., Tavernier, B., Dufouil, C., …. Elbaz, A. (2017). Gait speed and decline in gait speed as predictors of incident Dementia. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **72**, 655–661. doi:10.1093/gerona/glw110

Ebersbach, G., Dimitrijevic, M. R., & Poewe, W. (1995). Influence of concurrent tasks on gait: A dual-task approach. *Perceptual and Motor Skills*, **81**, 107–113. doi:10.2466/pms.1995.81.1.107

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**, 189–198. doi:10.1016/0022-3956(75)90026-6

Hassenstab, J., Ruvolo, D., Jasielec, M., Xiong, C., Grant, E., & Morris, J. C. (2015). Absence of practice effects in preclinical Alzheimer's disease. *Neuropsychology*, **29**, 940–948. doi:10.1037/neu0000208

Hausdorff, J. M., Schweiger, A., Herman, T., Yogev-Seligmann, G., & Giladi, N. (2008). Dual-task decrements in gait: Contributing factors among healthy older adults. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **63**, 1335–1343. doi:10.1093/gerona/63.12.1335

Hawkes, T. D., Siu, K. C., Silsupadol, P., & Woollacott, M. H. (2012). Why does older adults' balance become less stable when walking and performing a secondary task? Examination of attentional switching abilities. *Gait and Posture*, **35**, 159–163. doi:10.1016/j.gaitpost.2011.09.001

Hollman, J. H., Kovash, F. M., Kubik, J. J., & Linbo, R. A. (2007). Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait and Posture*, **26**, 113–119. doi:10.1016/j.gaitpost.2006.08.005

Hollman, J. H., McDade, E. M., & Petersen, R. C. (2011a). Normative spatiotemporal gait parameters in older adults. *Gait and Posture*, **34**, 111–118. doi:10.1016/j.gaitpost.2011.03.024

Hollman, J. H., Youdas, J. W., & Lanzino, D. J. (2011b). Gender differences in dual task gait performance in older adults. *American Journal of Men's Health*, **5**, 11–17. doi:10.1177/1557988309357232

Holtzer, R., Verghese, J., Xue, X., & Lipton, R. B. (2006). Cognitive processes related to gait velocity: Results from the Einstein Aging Study. *Neuropsychology*, **20**, 215–223. doi:10.1037/0894-4105.20.2.215

Holtzer, R., Wang, C., & Verghese, J. (2012). The relationship between attention and gait in aging: Facts and fallacies. *Motor Control*, **16**, 64–80. doi:10.1123/mcj.16.1.164

Klotzbier, T. J., & Schott, N. (2017). Cognitive-motor interference during walking in older adults with probable mild cognitive impairment. *Frontiers in Aging Neuroscience*, **9**, 350. doi:10.3389/fnagi.2017.00350

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). Orientation and attention. In M. D. Lezak (Ed.), *Neuropsychological Assessment* (pp. 337–374). New York, NY: Oxford University Press.

MacAulay, R. K., Allaire, T., Brouillette, R., Foil, H., Bruce-Keller, A. J., & Keller, J. N. (2016). Apolipoprotein E genotype linked to spatial gait characteristics: Predictors of cognitive dual task gait change. PloS one, **11**, e0156732. doi:10.1371/journal/pone.0156732

MacAulay, R. K., Allaire, T. D., Brouillette, R. M., Foil, H. C., Bruce-Keller, A. J., Han, H., …. Keller, J. N. (2015). Longitudinal assessment of neuropsychological and temporal/spatial gait characteristics of elderly fallers: Taking it all in stride. *Frontiers in Aging Neuroscience*, **7**, 34. doi:10.3389/fnagi.2015.00034

MacAulay, R. K., Brouillette, R. M., Foil, H. C., Bruce-Keller, A. J., & Keller, J. N. (2014). A longitudinal study on dual-tasking effects on gait: Cognitive change predicts gait variance in the elderly. *PLoS One*, **9**, e99436. doi:10.1371/journal.pone.0099436

MacAulay, R. K., Wagner, M. T., Szeles, D., & Milano, N. J. (2017). Improving sensitivity to detect mild cognitive impairment: Cognitive load dual-task gait speed assessment. *Journal of the International Neuropsychological Society*, **23**, 493–501. doi:10.1017/S1355617717000261

Machulda, M., Pankratz, V., Christianson, T., Mielke, M., Roberts, R., Ivnik, R., …. Petersen, R. (2013). Practice effects and longitudinal cognitive change in normal aging versus incident mild cognitive impairment and dementia in the Mayo Clinic Study of Aging. *Alzheimer's and Dementia*, **9**, P793. doi:10.1016/j.jalz.2013.05.1632

Matsuzawa, Y., Konishi, M., Akiyama, E., Suzuki, H., Nakayama, N., Kiyokuni, M., …. Kimura, K. (2013). Association between gait speed as a measure of frailty and risk of cardiovascular events after myocardial infarction. *Journal of the American College of Cardiology*, **61**, 1964–1972. doi:10.1016/j.jacc.2013.02.020

Mielke, M. M., Roberts, R. O., Savica, R., Cha, R., Drubach, D. I., Christianson, T., …. Petersen, R. C. (2013). Assessing the temporal relationship between cognition and gait: Slow gait predicts cognitive decline in the Mayo Clinic Study of Aging. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **68**, 929–937. doi:10.1093/gerona/gls256

Montero-Odasso, M., Oteng-Amoako, A., Speechley, M., Gopaul, K., Beauchet, O., Annweiler, C., & Muir-Hunter, S. W. (2014). The motor signature of mild cognitive impairment: Results from the gait and brain study. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **69**, 1415–1421. doi:10.1093/gerona/glu155

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. *Journal of the American Medical Association Neurology*, **74**, 857–865. doi:10.1001/jamaneurol.2017.0643

Muir, S. W., Speechley, M., Wells, J., Borrie, M., Gopaul, K., & Montero-Odasso, M. (2012). Gait assessment in mild cognitive impairment and Alzheimer's disease: The effect of dual-task challenges across the cognitive spectrum. *Gait and Posture*, **35**, 96–100. doi:10.1016/j.gaitpost.2011.08.014

Okoro, C. A., Zhong, Y., Ford, E. S., Balluz, L. S., Strine, T. W., & Mokdad, A. H. (2006). Association between the metabolic syndrome and its components and gait speed among U.S. adults aged 50 years and older: A cross-sectional analysis. *BMC Public Health*, **6**, 282. doi:10.1186/1471-2458-6-282

Petersen, R. C. (2004). Mild cognitive impairment as a diagnostic entity. *Journal of Internal Medicine*, **256**, 183–194. doi:10.1111/j.1365-2796.2004.01388.x

Plassman, B. L., Langa, K. M., Fisher, G. G., Heeringa, S. G., Weir, D. R., Ofstedal, M. B., …. Wallace, R. B. (2007). Prevalence of dementia in the United States: The aging, demographics, and memory study. *Neuroepidemiology*, **29**, 125–132. doi:10.1159/000109998

Rosano, C., Aizenstein, H., Brach, J., Longenberger, A., Studenski, S., & Newman, A. B. (2008). Special article: Gait measures indicate underlying focal gray matter atrophy in the brain of older adults. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **63**, 1380–1388. doi:10.1093/gerona/63.12.1380

Rosano, C., Aizenstein, H. J., Studenski, S., & Newman, A. B. (2007a). A regions-of-interest volumetric analysis of mobility limitations in community-dwelling older adults. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **62**, 1048–1055, doi:10.1093/Gerona/62.9.1048

Rosano, C., Brach, J., Studenski, S., Longstreth, W. T. Jr, & Newman, A. B. (2007b). Gait variability is associated with subclinical brain vascular abnormalities in high-functioning older adults. *Neuroepidemiology*, **29**, 193–200. doi:10.1159/000111582

Rosano, C., Longstreth, W. T. Jr, Boudreau, R., Taylor, C. A., Du, Y., Kuller, L. H., & Newman, A. B. (2011). High blood pressure accelerates gait slowing in well-functioning older adults over 18-years of follow-up. *Journal of the American Geriatrics Society*, **59**, 390–397. doi:10.1111/j.1532-5415.2010.03282.x

Rucker, J. L., McDowd, J. M., Mahnken, J. D., Burns, J. M., Sabus, C. H., Britton-Carpenter, A. J., …. Kluding, P. M. (2017). Multitasking in older adults with type 2 diabetes: A cross-sectional analysis. *PLoS One*, **12**, e0186583. doi:10.1371/journal.pone.0186583

Sheridan, P. L., & Hausdorff, J. M. (2007). The role of higher-level cognitive function in gait: Executive dysfunction contributes to fall risk in Alzheimer's disease. *Dementia and Geriatric Cognitive Disorders*, **24**, 125–137. doi:10.1159/000105126

Verghese, J., Holtzer, R., Lipton, R. B., & Wang, C. (2009). Quantitative gait markers and incident fall risk in older adults. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **64A**, 896–901. doi:10.1093/Gerona/glp033

Verghese, J., Lipton, R. B., Hall, C. B., Kuslansky, G., Katz, M. J., & Buschke, H. (2002). Abnormality of gait as a predictor of non-Alzheimer's dementia. *New England Journal of Medicine*, **347**, 1761–1768. doi:10.1056/NEJMoa020441

Verghese, J., Wang, C., Lipton, R. B., Holtzer, R., & Xue, X. (2007). Quantitative gait dysfunction and risk of cognitive decline and dementia. *Journal of Neurology, Neurosurgery, and Psychiatry*, **78**, 929–935. doi:10.1136/jnnp.2006.106914

Waite, L. M., Grayson, D. A., Piguet, O., Creasey, H., Bennett, H. P., & Broe, G. A. (2005). Gait slowing as a predictor of incident dementia: 6-year longitudinal data from the Sydney Older Persons Study. *Journal of the Neurological Sciences*, **229–230**, 89–93, doi:10.1016/j.jns.2004.11.009

Welsh-Bohmer, K. A., Ostbye, T., Sanders, L., Pieper, C. F., Hayden, K. M., Tschanz, J. T., …. Norton, M. C.; Cache Country Study Group. (2009). Neuropsychological performance in advanced age: Influences of demographic factors and Apolipoprotein E: Findings from the Cache County Memory Study. *Clinical Neuropsychologist*, **23**, 77–99. doi:10.1080/13854040801894730

Whitman, G. T., Tang, Y., Lin, A., Baloh, R. W., & Tang, T. (2001). A prospective study of cerebral white matter abnormalities in older people with gait dysfunction. *Neurology*, **57**, 990–994. doi:10.1212/wnl.57.6.990

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement Disorders*, **23**, 329–342; quiz 472. doi:10.1002/mds.21720