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The Relationship Between Attention and Gait in Aging: Facts and Fallacies

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Abstract

The current study critically assessed the relationship between cognitive functions and gait in nondemented older adults. Quantitative measures of gait (velocity, cadence, and a coefficient of variance in stride length) were assessed in single and dual-task conditions. Three cognitive factors captured the domains of Executive Attention, Verbal IQ, and Memory. Linear regressions showed that Executive Attention was related to velocity in both walking conditions. However, Memory and Verbal IQ were also related to velocity. Memory was related to Cadence in both walking conditions. Executive Attention was related to the coefficient of variance in stride length in both walking conditions. Linear mixed effects models showed that dual-task costs were largest in velocity followed by cadence and the coefficient of variance in stride length. The relationship between cognitive functions and gait depends, in part, on the analytic approach used, gait parameters assessed, and walking condition.

Keywords

gerontology; motor control; aging

Decline in gait performance in aging is common, and is associated with increased risk of developing a range of adverse outcomes including higher rates of morbidity and mortality, more hospitalizations, and poorer quality of life (Allan, Ballard, Burn, & Kenny, 2005; Hirvensalo, Rantanen, & Heikkinen, 2000; Newman, Haggerty, Kritchevsky, Nevitt, & Simonsick, 2003; Newman et al., 2006; Simonsick, Montgomery, Newman, Bauer, & Harris, 2001; Verghese et al., 2006). Further, longitudinal studies have shown that lower walking capacity (Abbott et al., 2004; Weuve et al., 2004) and presence of clinical gait abnormalities (Verghese, Lipton et al., 2002) are associated with increased risk of incident dementia. These latter findings suggest that the decline in cognitive function, as seen in dementia, and gait in older adults may not only coexist temporally but could possibly be linked to shared neural substrates.

Identifying the cognitive correlates of gait in aging is attractive for a number of reasons. Currently, the brain substrates and neural networks underlying gait are not well understood (Snijders, van de Warrenburg, Giladi, & Bloem, 2007), whereas, those substrates and networks underlying cognitive functions are being rapidly delineated (Stufflebeam & Rosen, 2007). Hence, inferences regarding cortical control of gait may be indirectly studied by examining its associations with cognitive functions (Holtzer, Verghese, Xue, & Lipton, 2006). In addition, specific cognitive functions that can be remediated (Sturm, Willmes, Orgass, & Hartje, 1997; Willis et al., 2006) and possibly enhanced in nondemented older

adults (Wolinsky et al., 2006), have been linked to gait performance in aging. Establishing causal links between specific cognitive functions and gait might also suggest that enhancing the former through remediation interventions may generalize to gains on the latter as well.

Most studies examining the relationship between cognitive functions and gait in aging have focused on attention and executive functions with the results typically showing that increased levels of attention are associated with better gait performance (Scherder et al., 2007). The focus on attention makes intuitive sense, and is also consistent with a large corpus of research indicating that attention resources decline in aging (Craik, 1982; McDowd & Shaw, 2000). Studies examining associations between attention and gait have used analytic approaches that can be broadly divided into two general classes. Dual-task methods require the participants to walk and perform a secondary interference task. The advantage of using the dual-task approach is that attention demands are experimentally manipulated. Hence, it is possible to make inferences about the causal effect of attention resources on gait and mobility performance (Camicioli, Howieson, Lehman, & Kaye, 1997; Li, Lindenberger, Freund, & Baltes, 2001; Lindenberger, Marsiske, & Baltes, 2000; Shkuratova, Morris, & Huxham, 2004; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002). Allocation of attention to concurrent and competing tasks represents executive processes (Baddeley, 1992; Baddeley & Logie, 1999) that are sensitive to aging (Holtzer, Burright, & Donovan, 2004; Holtzer, Stern, & Rakitin, 2004, 2005). However, dual-task methodology can be challenging in terms of both implementation and interpretation (Pashler, 1994). Specifically, with respect to gait, the validity and generalizability of such studies are difficult to establish because the paradigms used were not standardized in terms of the selection and measurement of the individual tasks as well as the administration instructions. Seminal work showed that when dual-tasking older adults prioritized walking over a secondary memory task and optimized walking when given external aids; whereas young individuals optimized memory task performance (Li et al., 2001). A later cohort study of nondemented older adults further clarified that experimentally manipulating task prioritization (i.e., dual-task instructions) had differential effect on gait measures but not on the secondary verbal task (Verghese et al., 2007). Individual differences in negotiating the demands of dual-tasks (or any other cognitive paradigms) are expected. However, for replication and validation purposes, it is imperative to provide explicit task administration instructions. The reliability and validity of the gait protocol used herein has been reported in separate study (Verghese, Wang, Lipton, Holtzer, & Xue, 2007) and examined in relation to outcomes of interest such as falls (Verghese et al., 2002). The second class of studies correlated gait performance with standardized measures of attention and executive function that were assessed independently of gait (Atkinson et al., 2007; Ble et al., 2005; Holtzer et al., 2006; Inzitari et al., 2007). Establishing causality is more difficult using this method because attention demands are not experimentally manipulated. However, it presents an advantage in that examining the cognitive correlates of gait is not limited to attention only. For instance, verbal IQ and memory were related to gait velocity as well (Holtzer et al., 2006). In addition, as mentioned earlier, rapid progress has been made in identifying the neural correlates of specific cognitive functions. Thus, a relationship between gait and cognitive functions other than attention and executive function, might provide additional insights into the neural substrates of gait.

Typically, the two approaches mentioned above have not been used in the same study to assess convergent evidence for the relationship between attention and quantitative measures of gait in aging. Further, it is noteworthy that many studies use velocity to assess gait performance. Consequently, associations of cognitive functions with other gait parameters, which are possibly influenced by cortical and subcortical control mechanisms different than those affecting speed, are not well studied. Notable exceptions are recent studies indicating that variability in stride length is related to executive functions, falls, and Alzheimer's

disease (Hausdorff, 2005, 2007; Springer, Giladi, Peretz, Yogev, Simon, & Hausdorff, 2006) or that variability in different gait measures was related to cognitive impairment (Brach, Studenski, Perera, VanSwearingen, & Newman, 2008). Further, our work also revealed that quantitative measures of gait can be reduced to three domains, which include speed cadence and variability (Verghese et al., 2007). Therefore, the objective of the current study was threefold: (1) assess convergent evidence for the association between attention and executive function and gait speed using the dual-task and correlative approaches discussed earlier within the same sample. That is, we aimed to determine whether different analytic approaches yielded consistent findings in characterizing the relationship of attention and executive function with gait speed; (2) evaluate divergent evidence for the role of attention and executive function in explaining performance characteristics in gait parameters other than speed. Stated differently, is there a differential relationship between attention and executive function and quantitative gait measures other than speed such as cadence, and variability in stride length (see methods for details); (3) determine whether other cognitive domains (memory and verbal IQ) were related to quantitative measures of gait.

Methods

Participants

Participants in this study were nondemented older adults ($n = 671$; mean age = 79 ys; percent female = 60) enrolled in the Einstein Aging Study (EAS) for whom complete cognitive and gait data were available. The EAS, a longitudinal study of aging and dementia, has used telephone-based screening procedures to recruit and follow a community-based cohort since 1999 (Lipton et al., 2003; Verghese et al., 2004). The primary aim of the EAS is to identify risk factors for dementia. Eligibility criteria required that participants be at least 70 years of age, reside in Bronx, and speak English. Exclusion criteria include severe audiovisual disturbances that would interfere with completion of neuropsychological tests, inability to ambulate even with a walking aid or in a wheelchair, and institutionalization. Potential participants over age 70 from the Center for Medicaid Medicare Services population lists of Medicare eligible individuals were first contacted by letter, then by telephone explaining the nature of the study. The telephone interview included verbal consent, a brief medical history questionnaire, and telephone-based cognitive screening tests (Lipton et al., 2003). Following the interview, participants who met eligibility criteria over the phone were invited for further screening and evaluations at our clinical research center. Informed consents were obtained at clinic visits according to study protocols and approved by the local institutional review board. Participants were followed at yearly intervals.

Diagnosis of Dementia—Diagnoses of dementia were assigned according to the criteria of the *Diagnostic and Statistical Manual of Mental Disorders*, fourth edition (DSM-IV TR, 2000), as determined by a consensus clinical diagnostic case conference as previously described (Holtzer, Verghese, Wang, Hall, & Lipton, 2008). Clinical, functional and cognitive test performance, based on a structured clinical neuropsychological test battery (also see Holtzer et al., 2006; 2007), were used to determine diagnostic status. Alzheimer's disease was diagnosed according to the criteria for probable disease detailed by the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (McKhann, Drachman, Folstein, Katzman, Price & Stadlan, 1984). The State of California Alzheimer's Disease Diagnostic and Treatment Centers criteria was used to assign diagnoses of probable, possible, or mixed vascular dementia (Chui, Victoroff, Margolin, Jagust, Shankle, & Katzman, 1992). Neuroimaging was used to help determine the diagnosis of "probable" Alzheimer's disease or "probable" vascular dementia in subjects diagnosed with dementia. We have reported good agreement between clinical diagnoses of Alzheimer's disease, Crystal, Dickson, Davies, Masur,

Grober, & Lipton, 2000) vascular dementia, (Verghese, Lipton, Hall, Kuslansky, Katz, & Buschke, 2002), and dementia with Lewy bodies, (Verghese, Crystal, Dickson, & Lipton, 1999) and pathological findings in our study. Based on these diagnostic procedures a total of 671 EAS nondemented subjects, with cognitive and gait data were eligible to participate in the current study.

Measures

Cognitive Function—a comprehensive battery of neuropsychological tests, validated for use in aging populations (Katzman et al., 1989; Masur, Sliwinski, Lipton, Blau, & Crystal, 1994; Sliwinski, Buschke, Stewart, Masur, & Lipton, 1997) provided detailed information regarding the participants' neuropsychological function. The following tests were incorporated into the neuropsychological battery: the Vocabulary (total score), Information (total score), Digit Span (total forward and backward), Digit Symbol (total number correct), and Block Design (total score) subtests of the Wechsler Adult Intelligence Scale—Revised [WAISR; (Wechsler, 1981)]; the Free and Cued Selective Reminding Test [FCSRT; total free recall; (Grober, Buschke, Crystal, Bang, & Dresner, 1988)]; a 15-item abbreviated version of the Boston Naming Test [BNT; total correct excluding semantic cues; (Stern et al., 1992)]; letter fluency [FAS; total number of words (Benton, 1976)]; category fluency [using procedures from the Boston Diagnostic Aphasia Examination; animals, fruits and vegetables (Goodglass, 1983)]; and the Trail Making Test [seconds to completion for Forms A and B; (Reitan, 1958)].

The Blessed Information Memory Concentration test (BIMC; best score: 0 errors and worst possible score: 32 errors), is a screen of cognitive impairment that is highly related to functional status, and scores of 8 or higher are associated with presence of dementia (Blessed, Tomlinson, & Roth, 1968). This test has high test-retest reliability (0.86) and correlates well with the pathology of Alzheimer disease (Fuld, 1978; Grober et al., 1999).

Recent studies showed that factor analysis of this neuropsychological battery consistently yielded three statistically orthogonal latent cognitive factors capturing the domains of Executive Attention, Verbal IQ and Verbal Memory (Holtzer et al., 2007; Holtzer et al., 2006). The Executive Attention factor encapsulates facets of higher order cognitive abilities that are typically considered representative of attention and executive processes. Individual tests that contribute to this factor are mostly timed and visually mediated. The Memory factor represents free recall and semantic verbal memory. The Verbal IQ factor represents verbal functions that in general appear less sensitive to the aging process.

Quantitative Gait Assessment—Research assistants conducted quantitative gait evaluations independent of the clinical evaluation. Quantitative gait variables were collected by using a 12-ft instrumented walkway (180 × 35.5 × 0.25 in.) with embedded pressure sensors (GAITRite, CIR systems, Havertown, PA). Excellent reliability and validity for GAITRite assessments were reported in previous research (Bilney, Morris, & Webster, 2003; Brach et al., 2008). The quantitative gait assessment provides several parameters. However, our previous research showed that these quantitative gait parameters can be reduced empirically to three orthogonal domains (Verghese et al., 2007). For the analyses reported herein and for the sake of comparability with prior work we focused on three individual gait parameters that represent the three gait domains reported by Verghese et al. (2007). Velocity, cm/s, is the distance covered on two trials by the ambulation time. Stride length, cm, is the distance between heel points of two consecutive footfalls of the same foot. Variability in length between strides is reported as the coefficient of variation (standard deviation/mean) × 100. Cadence, steps/min, is the number of steps taken in a minute.

Walking protocol: Participants were asked to walk on the instrumented walkway in a well-lit hallway at their “normal walking speed” for two trials without any attached monitoring devices (single task condition). Start and stop points were marked by white lines on the floor and included 3 ft each for initial acceleration and terminal deceleration. Using protocols developed and validated with another sample (Verghese et al., 2002) we then asked the participants to walk the course for two trials while reciting alternate letters of the alphabet (dual-task condition). The participants were asked to pay equal attention to both talking and walking during the dual task. To reduce learning effects, participants were given practice trials on both the single and dual tasks to familiarize themselves with the procedure. The order of the initial letter on the interference task was randomly varied between *A* and *B* to minimize practice effects between trials. Participants did not reach plateau on either the single or dual-task conditions.

Covariates

Trained research assistants used structured clinical interview, and the study physician obtained medical history during the neurological examination independently of the structured clinical interview. Consistent with our previous studies (Holtzer, Verghese, Xue, & Lipton, 2006; Holtzer et al., 2007) dichotomous rating (presence or absence) of diabetes, chronic heart failure, arthritis, hypertension, depression, stroke, Parkinson’s disease, chronic obstructive lung disease, angina, and myocardial infarction was used to calculate a disease comorbidity summary score (range 0–10). Usage of psychotropic medications and falls history were also assessed during the structured clinical interview and neurological examination.

Statistical Analyses

Demographic characteristics, gait parameters, and general cognitive function as estimated by the Blessed Information–Memory–Concentration test (Blessed et al., 1968) were tabulated for the entire sample. Consistent with previous studies (Holtzer et al., 2007; Holtzer et al., 2006) the neuropsychological raw test scores were submitted to principal components factor analysis to reduce the number of measures. Because the principle-components analysis was run on the correlation matrix, the raw scores were normalized on the basis of the distribution of the entire sample. Varimax rotation was used to derive orthogonal factor scores ($M = 0$, $SD = 1$), and the minimum eigenvalue for extraction was set at 1. Each factor was defined as a linear combination of all the neuropsychological tests. However, statistical significance for the factor loadings was set at .5 to simplify the interpretation of the factor analysis and because loadings of .5 or greater are also considered to be practically significant (Hair, 1998). Separate linear regression analyses examined associations between the cognitive factors and gait performance assessed in single and dual-task conditions.

Linear mixed effects model was used to examine the effect of dual-task interference (i.e., single vs. dual-task walking conditions) on gait performance. The advantage of the linear mixed model is that the heterogeneity and correlation of gait measures under different conditions are taken into account (Laird & Ware, 1982). Furthermore, the changes in separate gait performance indices (velocity, cadence, CV of stride length) due to dual-task interference can be directly compared through the linear mixed effects model. All analyses reported controlled for sex, age, ethnicity, education, disease comorbidity, use of psychotropic medications and falls history.

Results

Demographic characteristics, neuropsychological test performance, general level of cognitive function, and gait performance indices were tabulated (see Table 1).

Table 1 shows that more women than men participated in this study. The mean education level was above high school diplomate. The mean Blessed score was low (2.2 ± 2.1) as expected given that this sample consisted of nondemented older adults who functioned independently in the community.

Correlative Approach

Factor analysis of the neuropsychological test scores yielded exactly three significant orthogonal factors that accounted for 63% of the variance in neuropsychological test scores. The three factors captured the domains of Executive Attention, Verbal IQ, and Memory with each of the factors accounting for 25, 23, and 15% of the variance in the neuropsychological tests, respectively (see Table 2).

Linear regressions examined associations between the cognitive factors and gait performance measured in single and dual-task conditions (see Table 3).

Table 3 reveals that associations between the cognitive factors and gait varied depending on the gait parameter assessed and the walking condition. Executive Attention, Verbal IQ and Memory were significant predictors of velocity when assessed in the single walking condition. Executive Attention and Memory but not Verbal IQ were significant predictors of velocity when assessed in the dual-task condition. Of the three cognitive factors only Memory was a significant predictor of Cadence in both the single and dual-task walking conditions. Of the three cognitive factors only the Executive Attention was a significant predictor of the CV of stride length in both the single and dual-task walking conditions.

In secondary analysis we examined the relationship between cognitive functions and performance on the verbal interference task. The cognitive factors served as predictors and the total number of errors produced during the two walking trials ($\text{mean} = 2.45 \pm 2.52$) served as the dependent measure. As previously described, analysis controlled for sex, age, ethnicity, education, disease comorbidity, use of psychotropic medications, and falls history. The overall regression was statistically significant ($R = .30$, $R^2 = .09$, $p = .05$). Executive attention was related to performance on the verbal task in the expected direction with higher factor scores predicting lower number of errors ($B = -0.564$, $\beta = -0.204$, $p = .003$). However, memory ($B = -0.048$, $\beta = -0.020$, $p = .761$) and Verbal IQ ($B = -0.138$, $\beta = -0.053$, $p = .479$) did not predict performance on the verbal interference task.

Dual-Task Approach

Linear mixed effects models revealed significant dual-task effects in gait velocity, estimate = -28.46 cm/sec (95% CI: -32.202 - -24.723 , $p < .0001$); cadence, estimate = -24.9638 steps/min (95% CI: -28.6573 — -21.2702 , $p < .0001$); and CV of stride length, estimate = 2.0675 (95% CI: 1.138 – 2.997 , $p < .0001$). These effects were in the expected direction in that velocity and cadence decreased whereas the CV of stride length increased due to dual-task interference resulting in worse gait performance.

The dual-task related changes in velocity, cadence and the CV of stride length were divided by their respective standard deviations. This ensured comparability across measures so that all changes were expressed in terms of *SD* units. Then, linear mixed effects model was used to directly and simultaneously compare the change, caused by the dual-task interference, in each gait parameter. The results revealed that dual-task costs were significantly larger in velocity compared with both cadence (difference = 0.14 , 95% CI: 0.10 – 0.17 , $p < .001$) and the CV of stride length (difference = 0.88 , 95% CI: 0.79 – 0.97 ; $p < .001$).

Discussion

The current study critically assessed the relationship between cognitive functions and gait in nondemented older adults. The findings showed that associations between cognitive functions and gait varied depending on the analytic approach used, gait parameters assessed, and walking condition. Overall, the dual-task and correlative approaches provided convergent evidence for the important role attention and executive functions have in predicting differences in gait performance in both single and dual-task conditions. Dual-task costs were observed in velocity, cadence and the CV of stride length directly implicating the allocation of attention resources as a key determinant of differences in these quantitative gait parameters. Consistent with these findings the correlative approach revealed that higher executive attention scores predicted faster gait velocity and lower (i.e., better) CV of stride length. Moreover, among the three cognitive factors only executive attention was related to the CV of stride length when assessed in both single and dual-task conditions. This finding is indeed consistent with the notion that increased within person variability in performance represents impaired top-down executive control processes (West, Murphy, Armilio, Craik, & Stuss, 1992).

However, replicating our previous findings (Holtzer et al., 2006) in a smaller subsample of the Einstein Aging study cohort, we found that memory and Verbal IQ were related to gait velocity as well. Hence, focusing exclusively on attention and executive function limits research efforts aimed at identifying cognitive and neural mechanisms of gait. Examining the relationship between cognitive function and cadence further supports the above statement. The correlative approach revealed that only the memory factor was related to cadence in both the single and dual-task walking conditions. This finding is consistent with a recent study (Verghese et al., 2007) demonstrating that rhythm, an empirical gait factor encapsulating cadence, was related to dementia and to decline in episodic memory function in the same cohort.

The associations of specific quantitative measures of gait performance with memory and verbal IQ are less intuitive than their relations with attention. Verbal IQ has been conceptualized as a proxy for cognitive reserve (Stern, 2002) while variability in memory has been established as a reliable and sensitive indicator of brain function in normal and demented older adults (Sliwinski, Hofer, Hall, Buschke, & Lipton, 2003). Slow gait velocity, which has been used to operationalize mobility disability in older adults (Cesari et al., 2005; Studenski et al., 2003), is an index of health and functional status in older adults (Cesari et al., 2005; Montero-Odasso et al., 2005). Hence, the relationship between gait velocity, memory and verbal IQ may be attributed to temporal covariation among these three measures due to their sensitivity to brain function and disease in older adults. However, although speculative, it remains to be evaluated whether the relationship of cadence with the risk of dementia (cf., Verghese et al., 2007) and verbal memory performance, as described herein, is attributed to underlying shared neural substrates.

It is noteworthy that of the cognitive factors only executive attention predicted performance differences on the verbal interference task in the expected direction in that higher factor scores predicted lower number of errors in reciting the alphabet while walking. This finding provides further validation to the dual-task manipulation used herein in that subjects allocated attention resources to both the walking and talking as evidenced by the association of executive attention scores with performance differences on both tasks. The negative effect of dual-task interference, although evident in each of the three gait parameters, was the largest in velocity, followed by cadence, and then CV of stride length. These findings indicate that taxing the individual's attention resources while walking has differential effect on gait performance depending on the specific parameters assessed. We speculate that the

reduced, though significant, dual-task effect observed on the CV of stride length may be explained by the notion that top-down executive processes are inherent in intraindividual variability (cf., Holtzer et al., 2008) whether assessed in single or dual-task conditions, although the high variability on this measure (see Table 1) might account for this finding as well.

While the dual-task and correlative approaches provided convergent evidence for the associations between Executive Attention and gait velocity, discrepancies were noted as well. How the seemingly contradictory findings from these two analytic approaches, as in the case of cadence and the CV of stride length, can be further explained? We submit that Attention is a multifaceted construct (Pashler, 1998, Posner & Petersen, 1990). Dual-tasking although sensitive to the aging process (Verhaeghen & Cerella, 2002; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003) captures but one facet of attention that is both theoretically and empirically separated from other facets of this construct (Miyake et al., 2000). It is noteworthy that the latent cognitive domain used in this and previous research (Holtzer et al., 2007; Holtzer et al., 2006) to measure executive attention is visually mediated and sensitive to processing speed. Further studies should evaluate whether and how specific facets of attention and executive functions are related to different parameters of gait.

Although the cortical and subcortical control of gait is not well understood it appears that the neural substrate underlying cadence and velocity maybe different. While stride length and velocity are thought to be controlled supraspinally by phasic output from the basal ganglia to the supplementary motor area, spinal and brainstem mechanisms may influence cadence (Drew, Prentice, & Schepens, 2004; Morris, Iansek, Matyas, & Summers, 1994). Whereas white matter abnormalities were related to gait variability (Rosano, Brach, Studenski, Longstreth, & Newman, 2007), speed (Starr et al., 2003) and balance (Kerber, Enrietto, Jacobson, & Baloh, 1998; Whitman, Tang, Lin, & Baloh, 2001), gray matter atrophy in the cerebellum and prefrontal cortex was associated with slower gait velocity (Rosano, Aizenstein, Studenski, & Newman, 2007) suggesting that both shared and separate brain regions and networks maybe implicated in controlling specific aspects of gait. One implication of these findings is that separate cognitive processes may have differential relationships with gait measures depending on the brain areas subserving both functions.

Clinical implications: At present, neuropsychological measures are not included in routine assessments of older adults who are at risk for developing gait impairments or falls. These findings are relevant to future research that will aim the determine whether inclusion of cognitive measures increases the specificity and sensitivity of risk assessment procedures designed to distinguish healthy individuals from those who will fall or develop gait impairments. Gait speed is the most common measure used in current risk assessment procedures (Cesari et al., 2005; Newman et al., 2006; Newman et al., 2003; Studenski et al., 2003). However, the findings reported herein provide strong evidence to the notion that cognitive functions have differential relationships with separate quantitative gait measures. Moreover, variability in stride length is a better predictor of falls (Hausdorff, 2005, 2007) including injurious falls (Verghese, Holtzer, Lipton & Wang, 2009) than gait velocity. Taken together, inclusion of quantitative measures of gait other than velocity may improve current clinical assessment procedures for individuals at risk for developing gait impairments or falls.

The relationship between cognitive functions and gait has implications with respect to treatment as well. Cognitive training enhances daily functions (Willis et al., 2006) and health-related quality of life (Wolinsky et al., 2006) in older adults. Moreover, cognitive training that focused on attention and executive functions enhanced gait velocity in normal walking and walking while talking in a small sample of sedentary older adults (Verghese,

Mahoney, Ambrose, Wang & Holtzer, 2010). The findings reported in the current study further suggest that enhancing distinct cognitive functions may have differential effect on individual quantitative gait parameters. For instance, while cognitive training of attention and executive functions resulted in improved gait velocity, it would be of interest to examine whether memory training has an effect on cadence. Finally, it remains to be evaluated whether targeting relevant cognitive functions for remediation can also enhance mobility in dementia and other patient populations.

The limitations of this study should be considered. The large sample consisted of nondemented older adults who reside and live independently in the community. The associations between cognitive functions and gait should also be examined in populations at risk (e.g., nursing homes) with known impairments in specific cognitive functions (e.g., Parkinson's disease or Alzheimer's disease) to further substantiate these findings. Prospective studies should also examine longitudinal effects of cognitive functions on decline in gait performance. Finally, as the nature of the interference task might have influenced the findings of this study, using dual-task paradigms with different interference tasks to examine the relationship between cognitive functions and gait is of interest.

In summary, this study critically evaluated the relationship between cognitive function and gait performance in aging. Future research should focus on how specific facets of attention, executive functions as well as other cognitive functions are related to separate aspects of gait, and how such associations might inform us about their underlying brain substrates and genetic determinants (Holtzer, Ozelius, Xue, Wang, Lipton, & Verghese 2010).

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Table 1

Summary of Sample Characteristics ($n = 671$; percent female = 60), General Cognitive Function, and Gait Performance

	Mean(SD)	Median	Range
Age years:	79 (5.2)	78.5	70–98
Education years:	13.8 (3.5)	13	3–25
Blessed total:	2.2 (2.1)	2	2–7
Vocabulary	46.4 (13.2)	48	9–70
BNT	11.8 (2.5)	12	4–15
Information	20.4 (5.9)	22	3–29
Letter Fluency	35.3 (12.9)	35	3–82
Digit Span	13.9 (3.6)	14	5–28
Block Design	21.0 (9.2)	21	1–61
Digit Symbol	41.2 (14.3)	40	1–86
Trails A (time, sec)	58.6 (23.8)	54	20–225
Trails B (time, sec)	136.0 (64.0)	123	36–300
FCSRT	31.5 (5.8)	32	11–48
Category Fluency	36.9 (9.1)	36	6–70
Gait Velocity single (cm/sec):	94.3 (23.7)	95	20–173
Gait Velocity dual-task (cm/sec):	71.2 (26.6)	70	11–177
Cadence single task	101.4(11.9)	101	37–135
Cadence dual-task:	82.4(21.1)	81	21.6–151
CV stride length single task:	4.2 (3.0)	3.5	0.15–31.2
CV Stride length dual-task:	6.1 (5.4)	4.9	0.38–62.4

Note: BNT = Boston Naming Test; FAS = Verbal Fluency; FCSRT = Free and Cued Selective Reminding Test—free recall condition.

Table 2

Results of the Principal Components Factor Analysis

Variable	Executive Attention	Verbal IQ	Memory
% of variance	25	23	15
Tests			
Digit Span	.529	.379	-.137
Block Design	.689	.257	-.058
Digit Symbol	.815	.138	.204
Trails: A (time)	-.627	.000	-.304
Trails: B (time)	-.700	-.207	-.277
Information	.028	.844	.067
Vocabulary	.208	.884	.103
BNT	.408	.564	.174
FAS	.273	.586	.357
Information	.028	.844	.067
FCSRT:	.073	.070	.894
Category Fluency	.312	.417	.629

Note: bold print indicates loading coefficients above.

BNT = Boston Naming Test; FAS = Verbal Fluency; FCSRT = Free and Cued Selective Reminding Test—free recall condition.

Table 3

Summary of Linear Regression Analyses Using the Cognitive Factors as Predictors and Gait Parameters as the Outcome Variables in Single and Dual-Task Conditions.

	Gait parameters											
	Velocity			Cadence			CV Stride length					
	Single	Dual-task	Single	Dual-task	Single	Dual-task	Single	Dual-task	Single	Dual-task	Single	Dual-task
R (R ²)	0.44 [†] (0.19)	0.39 [†] (0.16)	0.23 [†] (0.05)	0.26 [†] (0.07)	0.28 [†] (0.08)	0.29 [†] (0.09)						
B	β	β	β	β	β	β	β	β	β	β	β	β
Executive Attention	5.38	.227 [†]	4.7	.176 [†]	1.205	.106*	1.225	.058	-1.271	-1.220 [†]	-1.60	-2.38 [†]
Verbal IQ	2.59	.110*	1.57	.059	.710	.06	-.182	-.009	-.432	-.075	-.234	-.035
Memory	4.89	.204 [†]	5.07	.190 [†]	1.65	.139 [†]	2.4	.114 [†]	-.136	-.024	-.293	-.044

Analyses controlled for age, sex, education, ethnicity, medical comorbidity, psychotropic medications and falls history.

* P < 0.05;

[†] P < 0.01; B = unstandardized coefficient; β = standardized coefficient