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Cognitive Function, Gait, and Gait Variability in Older People: A Population-Based Study

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Background. Gait impairments are associated with falls and loss of independence. The study of factors associated with poorer gait may assist in developing methods to preserve mobility in older people. The aim of this study was to examine the associations between a range of cognitive functions and gait and gait variability in a population-based sample of older people.

Methods. Gait and intra-individual gait variability measures were obtained using the *GAITRite* walkway in a sample of older people, aged 60–85 years (N = 422), randomly selected from the Tasmanian electoral roll. Raw scores from a cognitive battery were subjected to principal component analyses deriving four summary domains: executive function/attention, processing speed, memory, and visuospatial ability. Multivariable linear regression was used to examine associations between cognitive domains and gait measures adjusting for age, sex, ambulatory activity, medication use, and mood.

Results. The mean age of the sample was 72.0 years (SD = 7.0), with 238 men (56%). Poorer executive function was independently associated with poorer performance in most absolute gait measures and with greater variability in double support phase and step time. Processing speed was associated with absolute gait measures and double support phase variability. Visuospatial ability was only associated with greater double support phase variability, independently of executive function and processing speed. Memory was not independently associated with any gait measure.

Conclusions. In community-dwelling older people, executive function/attention and processing speed were associated with many aspects of gait, whereas visuospatial ability may only play a role in double support phase variability.

Key Words: Gait—Gait variability—Cognitive function—Aging.

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GAIT and cognitive impairments, caused by aging or disease, commonly occur in older people (1–3) and have been shown to predict falls (4,5). However, the interrelationships between cognitive function and gait are relatively poorly understood. Studying these relationships may provide further insights into the neural substrates of gait control in aging and provide targets for therapeutic interventions to prevent mobility decline and falls in older people.

Existing studies have mainly focused on associations between executive function and/or attention and gait (6–10) or that of divided attention using a dual-task paradigm on gait control (8,11–18). However, the majority of studies have been limited in that they were from small samples of patients, volunteers, or high-functioning older people limiting generalizability to the wider community.

There have been few population-based studies examining the effects of specific cognitive domains on gait (19–23). Although these studies examined executive function (19–23), very few have examined other key cognitive domains such as memory (19,22) or processing speed (23), and none to our knowledge have examined visuospatial ability or modeled the independence of cognitive domains from each other. Furthermore, previous results are conflicting as to whether executive function is associated with gait under single-task condition (20,22,23) or not (19,21,23), which may be due to the different gait measures examined. Although the majority of population-based studies have investigated the associations between cognitive function and gait speed (20–22), its relationship with other gait variables may be useful to understand. For example, intra-individual gait variability is thought to be a better indicator of balance and the risk of falls than gait speed (4,24).

There are no population-based studies, to our knowledge, that have investigated the effects of a wide range of cognitive functions on gait speed, other absolute gait variables, and gait variability together. Therefore, we plan to extend

previous studies by examining the associations between a range of cognitive domains (executive function/attention, processing speed, memory, and visuospatial ability) and a range of gait and gait variability measures in a randomly selected population-based sample of older people. Specifically, we hypothesized that poorer executive function/attention would be associated with poorer performance in gait and gait variability measures. However, due to limited previous work in the field, we conducted exploratory analyses studying the relationship between other cognitive domains and gait.

Methods

Participants

The sample consisted of 422 participants in the Tasmanian Study of Cognition and Gait (TASCOG) conducted in Hobart, Tasmania, Australia. Eligible participants were aged 60–85 years inclusive, were residents of the region of southern Tasmania that is defined by postcodes 7000–7199, and were randomly selected from the Tasmanian electoral roll. They were excluded if they lived in residential care, were unable to walk without a gait aid, or had any contraindications to magnetic resonance imaging (eg, metal implants/clips, pacemaker, inability to lie flat for greater than 20 minutes, claustrophobia), a requirement of the overall study. The southern Tasmanian Health and Medical Human Research Ethics Committee approved this study.

Gait and Gait Variability

Absolute gait measures were obtained using the 4.6-m GAITRite system (CIR Systems, PA). Participants were required to complete six walks at usual pace and start and finish walking 2 m before and after the mat to allow a constant speed to be captured. No walking aids were permitted during the walks. Variables collected were gait speed, step time, step length, support base, and double support phase (DSP [25]). Gait speed is the distance travelled divided by ambulation time (cm/s); step time is the time elapsed from contact of one foot to contact of the next (ms); step length is the perpendicular distance between the heel of one footfall to the heel of the next footfall (cm); support base is the perpendicular distance from the heel of one footfall to the line of progression of the other foot (cm); DSP is the phase of the gait cycle when both feet are in contact with the ground (m/s and percentage), where measuring the percentage of the gait cycle allows identification of those with a short gait cycle, but a moderate DSP or vice versa. Intraindividual variability for each of the gait measures was calculated using the standard deviation (23,24) of the measure across all steps for all six walks. These gait variables were included as they represent temporal and spatial measures in both the frontal and sagittal plane, with the majority having been shown to load on to different domains using factor analysis (26). Gait speed is the most commonly reported variable and is predictive of a number of adverse health outcomes (27). Step length and step time are the determinants of gait speed and are clinically useful in assessing and treating gait disorders (28). Support base (frontal) and DSP (sagittal) represent balance control when walking. Intraindividual gait variability measures chosen in this study are not thought to represent the same construct (23) and have previously been associated with falls risk (4,24).

Cognitive Function

A battery of cognitive tests was conducted to assess the following fundamental and instrumental cognitive domains (29).

Fundamental functions: (a) *Executive function/attention*—using the Controlled Word Association Test (COWAT, using the letters F, A, and S; [30]); Category Fluency (animals, [30]); the Victoria Stroop test—comprised of three subtests (i) colored dots, (ii) colored everyday words, and (iii) colored color names (eg, the word blue written in red ink; [31]); and the Digit Span subtest of the Wechsler Adult Intelligence Scale—Third Edition (WAIS-III [32]) and (b) *Processing speed*—using the Symbol Search and Digit Symbol Coding subtests of the WAIS-III (32); Instrumental functions: (a) *Visuospatial ability*—using the Rey Complex Figure copy task (30) and (b) *Memory*—using the Hopkins Verbal Learning Test—revised (verbal memory) generating scores for total immediate recall, delayed recall, and recognition memory (30) and a delayed reproduction after 20 minutes of the Rey Complex Figure (visual memory [30]).

Other Measurements

Physical activity was measured using a Yamax Digi-Walker SW-200 pedometer worn over seven consecutive days. Participants were required to complete a 7-day diary of daily steps, times worn, and times not worn. Recordings for days on which the pedometer was worn for less than 8 hours were excluded when calculating mean number of steps per day. Mood was measured using the 15-item Geriatric Depression Scale (33). Over-the-counter and prescription medicines were recorded, and participants were classified as taking a psychoactive medication if they were using any of the following: antidepressants, antipsychotics, sedative/hypnotics, antiepileptics, or antiparkinsonian agents. They were also classified as either using or not using blood pressure–lowering drugs.

Data Analysis

Similar to our previous work (34), and as described earlier, the raw scores of cognitive tests were grouped into the specific cognitive domains of executive function/attention, processing speed, and memory, and then subjected to data

reduction using principal components analysis. A summary cognitive component was thus derived to represent each of these domains. Regression scores were then generated for each of these components using Thomson's method (35) and were used as variables in further analysis. The Rey Complex Figure Copy task was the sole test of visuospatial ability, and hence its raw score was used for analyses.

Univariable regressions were first performed to examine associations of cognitive factors with gait and gait variability. Multivariable linear regression was then used to examine associations adjusting for age, sex, physical activity, medication use, mood, and years of education. In the case of analyses for memory and visuospatial ability, additional adjustment was made for processing speed and executive function/attention because the former functions may be dependent on the latter (29). Gait speed was assessed for its potential role as a confounder or as an intermediate in the relationship between cognitive function and gait variability and was adjusted for accordingly. If adding gait speed into the regression model changed the coefficients for both cognitive function and gait speed by more than 15%, gait speed was deemed a confounder. Based on this, regressions of step time variability and support base variability were thus additionally adjusted for gait speed. Fractional polynomials were used to assess the assumptions of the final models.

Results

The mean age of the sample (N = 422) was 72.0 years (SD = 7.0) with 238 men (56.4%). The sample response proportion was 52% (n = 804) with nonresponders generally older ($p < .01$) and with a higher self-reported incidence of hypertension ($p = .03$). Demographic, gait, and cognitive test characteristics are shown in Table 1.

Loadings of cognitive tests on the cognitive components derived from the principal component analysis were very similar to our previously reported analyses (34) and are shown in the Supplementary Table 1. Univariable and multivariable regressions between executive function/attention and processing speed and the gait and gait variability measures are shown in Table 2. In the univariable regressions, poorer executive function/attention and processing speed were associated with poorer performance on all of the absolute gait measures (all $p < .01$) and with greater variability in all gait measures (all $p < .05$) except step time. After adjusting for confounders, processing speed remained independently associated with all absolute gait measures (all $p < .05$) and executive function/attention was associated with absolute gait measures ($p < .05$) except for step time and support base. With respect to gait variability, executive function/attention was independently associated with step time and DSP variability ($p < .05$), whereas processing speed was associated with DSP variability ($p = .02$).

Associations between memory and visuospatial ability and the gait and gait variability measures are shown in Table 3. In univariable analyses, memory was associated with poorer performance on all of the absolute gait measures (all $p < .01$), whereas poorer visuospatial ability was associated only with slower gait speed, shorter step length, and smaller DSP (all $p < .05$). Poorer memory was only associated with greater step time variability, and poorer visuospatial ability was associated with greater variability in both step length and DSP (all $p < .001$). After adjusting for putative confounders, memory was only associated with DSP (%), but this disappeared after further adjusting for executive function/attention and processing speed ($\beta = -0.193$, 95% CI = −0.488, −0.103). Visuospatial ability was not associated with any of the absolute gait measures. However, visuospatial ability was independently associated with greater DSP variability ($p = .04$), even after adjusting for executive function/attention or processing speed. Visuospatial ability contributed the greatest proportion of the variance to DSP variability (R^2 = 0.113), followed by executive function (R^2 = 0.107) and processing speed (R^2 = 0.039). Memory was not associated with any gait variability measures ($p > .05$).

Table 1. Participant Characteristics (n = 422)

Variables	Mean (*SD*/%)
Age (y)	72.0 (7.0)
Male sex (*n*/%)	238 (56.4)
Geriatric depression scale score	2.05 (2.3)
Psychoactive drugs (*n*/%)	88 (20.9)
Absolute gait measures	
Gait speed (cm/s)	113.5 (21.6)
Step time (ms)	548.67 (53.7)
Step length (cm)	61.5 (9.4)
Support base (cm)	9.99 (2.9)
DSP (ms)	255.91 (59.1)
DSP (% of gait cycle)	23.2 (3.9)
Gait variability measures	
Step time variability (ms)	22.4 (13.8)
Step length variability (cm)	2.73 (0.93)
Support base variability (cm)	2.12 (0.69)
DSP variability (ms)	20.9 (11.2)
Cognitive tests	
Digit span	15.8 (3.8)
Category fluency	17.05 (5.0)
COWAT	35.9 (13.3)
Stroop dot (s)	16.1 (5.3)
Stroop words (s)	22.0 (10.6)
Stroop colors (s)	39.2 (22.7)
Digit symbol coding	49.8 (15.3)
Symbol search	22.7 (7.6)
Rey Complex Figure copy	32.1 (4.7)
Rey Complex Figure delay	14.8 (7.0)
Hopkins immediate recall	22.0 (6.3)
Hopkins delayed recall	7.5 (3.1)
Hopkins recognition	21.6 (2.9)

Note: SD = standard deviation; COWAT = Controlled Oral Word Association Test.

Table 2. Univariable and Multivariable Linear Regressions Between Cognitive Components and Gait Measures

	Regression Coefficient (β), 95% Confidence Interval (CI)			
	Univariable regression		Multivariable regression	
Gait measures	Executive/attention	Processing speed	Executive/attention	Processing speed
Gait speed (cm/s)	–3.66 (–4.75,–2.57)*	6.23 (4.77,7.68) *	–1.57 (–2.67,–0.47)†	2.42 (0.78,4.06)†
Step time (ms)	6.45 (3.68,9.22)*	–10.01 (–13.82,–6.19)*	2.57 (–0.41,5.55)	–4.95 (–9.36,–0.55)‡
Step length (cm)	–1.36 (–1.84,–0.88)*	2.45 (1.80,3.09)*	–0.60 (–1.04,–0.16)†	0.82 (0.16,1.47)‡
Support base (cm)	0.31 (0.16,0.46)*	–0.47 (–0.68,–0.26)*	0.14 (–0.03,0.30)	–0.27 (–0.52,–0.29)‡
DSP (ms)	7.45 (4.41,10.49)*	–12.87 (–17.02,–8.73)*	3.73 (0.49,6.98)‡	–5.68 (–10.52,–0.84)‡
DSP (%)	0.41 (0.22,0.61)*	–0.74 (–1.01,–0.46)*	0.25 (0.05,0.46)‡	–0.31 (–0.62,–0.004)‡
Gait variability measures				
Step time (ms)	–0.004 (–0.02,0.01)	–0.0001 (–0.02,0.02)	0.78 (0.05,1.51)‡	–0.69 (–1.78,0.40)
Step length (cm)	0.07 (0.03,0.12)†	–0.14 (–0.20,–0.07)*	0.004 (–0.05,0.05)	–0.04 (–0.12,0.04)
Support base (cm)	0.04 (0.01,0.08)‡	–0.07 (–0.12,–0.02)†	0.03 (–0.01,0.07)	–0.04 (–0.10,0.02)
DSP (ms)	0.001 (0.001,0.002)*	–0.002 (–0.003,–0.001)*	0.78 (0.13,1.44)‡	–1.13 (–2.10,–0.15)‡

Notes: DSP = double support phase. Higher scores in executive/attention reflect worse function. Higher scores in processing speed reflect better function. Multivariable regressions adjusted for age, sex, medication use, mood, physical activity, and years of education; step time variability and support base variability additionally adjusted for gait speed. Univariable but not multivariable associations remained statistically significant after adjusting for multiple comparisons ($p < .00125$).
*$p < .001$. †$p < .01$. ‡$p < .05$.

Table 3. Univariable and Multivariable Linear Regressions Between Cognitive Components and Gait Measures

	Regression Coefficient (β), 95% Confidence Interval			
	Univariable regression		Multivariable regression	
Gait measures	Memory	Visuospatial ability	Memory	Visuospatial ability
Gait speed (cm/s)	3.37 (2.02,4.73)*	1.18 (0.75,1.61)*	0.94 (–0.44,2.32)	0.28 (–0.16,0.71)
Step time (ms)	–7.00 (–10.37,–3.62)*	–0.78 (–1.89,0.32)	0.24 (–3.44,3.93)	–0.08 (–1.25,1.08)
Step length (cm)	1.01 (0.41,1.61)*	0.59 (0.41,0.78)*	0.41 (–0.14,0.96)	0.16 (0.01,0.33)
Support base (cm)	–0.40 (–0.58,–0.21)*	–0.04 (–0.10,0.02)	–0.04 (–0.25,0.16)	–0.04 (–0.10,0.03)
DSP (ms)	–8.61 (–12.34,–4.88)*	–1.77 (–2.98,–0.56)†	–3.10 (–7.15,0.95)	0.15 (–1.13,1.43)
DSP (%)	–0.52 (–0.76,–0.28)*	–0.12 (–0.20,–0.04)†	–0.33 (–0.59,–0.08)†	–0.02 (–0.07,0.10)
Gait variability				
Step time (ms)	–0.02 (–0.03,–0.005)*	0.003 (–0.001,0.007)	0.54 (–0.36,1.44)	–0.28 (–0.56,0.0004)
Step length (cm)	–0.03 (–0.09,0.03)	–0.03 (–0.05,–0.01)†	0.07 (0.0005,0.13)	–0.01 (–0.03,0.01)
Support base (cm)	–0.03 (–0.07,0.01)	–0.01 (–0.02,0.005)	0.02 (–0.03,0.07)	–0.004 (–0.02,0.01)
DSP (ms)	–0.004 (–0.001,0.0004)	–0.001 (–0.001,–0.0003)*	0.55 (–0.27,1.37)	–0.34 (–0.60,–0.09)†

Notes: DSP = double support phase. Higher scores in memory and visuospatial ability reflect better function. Multivariable regression adjusted for age, sex, medication use, mood, physical activity, and years of education; step time variability and support base variability additionally adjusted for gait speed. Univariable but not multivariable associations remained statistically significant after adjusting for multiple comparisons correction ($p < .00125$).
*$p < .001$; †$p < .01$; ‡$p < .05$.

Discussion

The findings of this population-based study were that executive function/attention and processing speed were associated with poorer performance on most absolute gait measures. Memory and visuospatial ability had no independent effects on absolute gait measures after taking into account the effects of executive function and processing speed. Executive function/attention was independently associated with variability in DSP and step time, whereas processing speed and visuospatial ability, but not memory, were independently associated with only DSP variability.

The major strength of this study is its use of a large population-based sample to examine, for the first time, the associations of a range of cognitive tests covering multiple domains with clinically relevant absolute gait and gait variability measures (28). We carefully adjusted for potential confounders, and in the models for memory and visuospatial function, we also adjusted for fundamental cognitive functions (executive function/attention and processing speed). The study response rate was moderate and because nonresponders were older, we may have underestimated associations. The gait walkway used was relatively short and gait variability was calculated from a minimum of 24 strides. However, Hollman and colleagues (36) reported that less than 20 strides still showed a moderate test–retest reliability in gait variability. As this is a cross-sectional study (a limitation of this study), it is uncertain from these results whether the associations reflect the cognitive control of gait or whether there is simply a shared neural substrate between the two functions and that impaired cognition is a marker for poor gait (or vice versa). A causal relationship between declining cognition and gait is best studied in a longitudinal fashion. It is also possible that the Digit Symbol and Symbol Search tests may be capturing some element of

visual ability but they are primarily tests of psychomotor speed (31). Finally, given the number of comparisons, there is a potential that some of the results represent Type I errors and that confirmation in an independent sample is required to confirm these associations.

Consistent with previous research (10,20,22), we showed that poorer executive function/attention was associated with slower gait speed. To our knowledge, associations between cognition and other absolute gait measures that determine gait speed (28) have not been examined in population-based samples. A novel finding of this study was that the association with gait speed might be explained by the association between executive function/attention and only one of its determinants, step length, rather than step time. Interestingly others have suggested that while gait speed and step length may reflect shared neural substrates that subserve these cognitive measures, particularly the connections between the frontal cortex and basal ganglia (30,31,37), step time may rely more on brainstem and spinal cord mechanisms (37). Slower processing speed was associated with all absolute gait measures. Further work is required to determine whether this is due to slowing in cortical, spinal, and/or peripheral systems.

We also examined associations between cognitive function and gait variability measures. Gait variability is the fluctuation in a gait measure from one step to the next and thought to represent disruption in motor or postural control (38). Gait variability is also thought to be a more sensitive predictor of falls and mobility decline than gait speed (24) and is increased in disease of the central nervous system such as Parkinson's and Alzheimer's diseases (39). We found associations between executive function/attention and processing speed for temporal, but not spatial, gait variability measures. This is consistent with previous findings in younger people of increasing stride time variability, but not stride length variability, under dual-task cognitive interference (23) and suggests that stronger associations between temporal versus spatial variability measures may be due to the timing component of the cognitive tests (4,40).

A novel finding in our study was that visuospatial function, the representation of objects in a spatial array (eg, a person in relation to their environment or the relative position of a table in a room) was independently associated with DSP variability. DSP variability is associated with increased risk of falls (41) and also with greater postural sway with the eyes closed (42,43). Visuospatial ability may alter DSP variability through its association with reduced postural control (44,45) and may well mediate some of the effect of visuospatial function on falls risk. The parietal lobes are known to play an important role in most visuospatial tasks, suggesting that this region and associated networks are important in the interaction between gait and cognition. Although we adjusted associations between visuospatial function and gait for executive function, it is possible that we did not measure all aspects of the later. Therefore, some of the associations between the Rey Complex Figure and DSP variability could still be explained by executive function. Further research is required to determine if interventions or compensatory mechanisms to target visuospatial ability can improve DSP variability and reduce falls risk.

In contrast to previous research showing decline in gait speed in patients with Alzheimer's disease (19), but consistent with another population-based studies (31), we found that memory was not independently associated with any of the absolute or gait variability measures after adjusting for fundamental cognitive functions. It is possible that the lack of association may be that the tests used to measure memory may not have been sufficiently sensitive. However, the Hopkins Verbal Learning Test and Rey Complex Figure delay task are robust tests of this function with high validity (46), making it less likely that measurement error may have been responsible for the lack of associations. Another explanation may be that the sample in our study was, on average relatively cognitively healthy, with 75% of participants achieving high raw scores (>30) on the Rey Complex Figure copy test. We may have thus underestimated the true magnitude of associations by our exclusion criteria. It is possible that associations may have been different in those with dementia or mild cognitive impairment. We did not have information on mild cognitive impairment, but similar studies have reported a prevalence of between 3% and 19% (47). Excluding those with prior dementia (n = 2) made no difference to the results.

Although cross-sectional, the results of this population-based study suggest that the relationship between cognitive function and gait goes beyond executive function and gait speed. Interventions to maintain or improve mobility in older age may need to incorporate methods to maintain cognitive function in addition to traditional strength and balance training. Importantly, different gait measures may have different related or underlying cognitive functions, and this has implications for the design of therapeutic interventions. For example, in a program designed to improve walking speed, those with reduced step time would benefit from interventions to improve processing speed, whereas those with reduced step length would also benefit from interventions to improve executive function. Initial research suggests that interventions to improve cognitive function may include increasing physical activity, cognitive training programs, and pharmacotherapy.

Conclusion

In a population-based study of community-dwelling older people, executive function/attention and processing speed were associated with poorer performance on most absolute gait measures. Poorer executive function was associated with temporal gait variability, with the addition of processing speed and visuospatial ability for DSP variability. Poorer cognitive function seems to have the greatest

impact on DSP variability, an important factor in balance control during walking. The results of this study increase understanding of the cognitive control of gait and suggest possible targets for interventions aimed at preventing mobility decline in older people.

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Conflicts of Interest

There are no conflicts of interest for any author.

Supplementary Material

Supplementary material can be found at: http://biomedgerontology.oxfordjournals.org/

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References

1. Winter DA, Patla AE, Frank JS, Walt SE. Biomechanical walking pattern changes in the fit and healthy elderly. *Phys Ther*. 1990;70:340–347.
2. Dobbs RJ, Charlett A, Bowes SG, et al. Is this walk normal? *Age Ageing*. 1993;22:27–30.
3. Wolinsky FD, Bentler SE, Hockenberry J, et al. A prospective cohort study of long-term cognitive changes in older Medicare beneficiaries. *BMC Public Health*. 2011;11:710.
4. Callisaya ML, Blizzard L, Schmidt MD, et al. Gait, gait variability and the risk of multiple incident falls in older people: a population-based study. *Age Ageing*. 2011;40:481–487.
5. Anstey KJ, von Sanden C, Luszcz MA. An 8-year prospective study of the relationship between cognitive performance and falling in very old adults. *J Am Geriatr Soc*. 2006;54:1169–1176.
6. Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. *Mov Disord*. 2008;23:329–342.
7. Beauchet O, Annweiler C, Allali G, Berrut G, Herrmann FR, Dubost V. Recurrent falls and dual task-related decrease in walking speed: is there a relationship? *J Am Geriatr Soc*. 2008;56:1265–1269.
8. Beauchet O, Kressig RW, Najafi B, Aminian K, Dubost V, Mourey F. Age-related decline of gait control under a dual-task condition. *J Am Geriatr Soc*. 2003;51:1187–1188.
9. Hausdorff JM, Yogev G, Springer S, Simon ES, Giladi N. Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Exp Brain Res*. 2005;164:541–548.
10. Rosano C, Simonsick EM, Harris TB, et al. Association between physical and cognitive function in healthy elderly: the health, aging and body composition study. *Neuroepidemiology*. 2005;24:8–14.
11. Sheridan PL, Solomont J, Kowall N, Hausdorff JM. Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer's disease. *J Am Geriatr Soc*. 2003;51:1633–1637.
12. Lundin-Olsson L, Nyberg L, Gustafson Y. "Stops walking when talking" as a predictor of falls in elderly people. *Lancet*. 1997;349:617.
13. Springer S, Giladi N, Peretz C, Yogev G, Simon ES, Hausdorff JM. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. *Mov Disord*. 2006;21:950–957.
14. Priest AW, Salamon KB, Hollman JH. Age-related differences in dual task walking: a cross sectional study. *J Neuroeng Rehabil*. 2008;5:29.
15. Hollman JH, Kovash FM, Kubik JJ, Linbo RA. Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait Posture*. 2007;26:113–119.
16. Grabiner MD, Troy KL. Attention demanding tasks during treadmill walking reduce step width variability in young adults. *J Neuroeng Rehabil*. 2005;2:25.
17. van Iersel MB, Ribbers H, Munneke M, Borm GF, Rikkert MG. The effect of cognitive dual tasks on balance during walking in physically fit elderly people. *Arch Phys Med Rehabil*. 2007;88:187–191.
18. Ebersbach G, Dimitrijevic MR, Poewe W. Influence of concurrent tasks on gait: a dual-task approach. *Percept Mot Skills*. 1995;81:107–113.
19. van Iersel MB, Kessels RP, Bloem BR, Verbeek AL, Olde Rikkert MG. Executive functions are associated with gait and balance in community-living elderly people. *J Gerontol A Biol Sci Med Sci*. 2008;63:1344–1349.
20. Coppin AK, Shumway-Cook A, Saczynski JS, et al. Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. *Age Ageing*. 2006;35:619–624.
21. Ble A, Volpato S, Zuliani G, et al. Executive function correlates with walking speed in older persons: the InCHIANTI study. *J Am Geriatr Soc*. 2005;53:410–415.
22. Holtzer R, Verghese J, Xue X, Lipton RB. Cognitive processes related to gait velocity: results from the Einstein Aging Study. *Neuropsychology*. 2006;20:215–223.
23. Brach JS, Studenski S, Perera S, VanSwearingen JM, Newman AB. Stance time and step width variability have unique contributing impairments in older persons. *Gait Posture*. 2008;27:431–439.
24. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil*. 2001;82:1050–1056.
25. CIR Systems Inc. The GAITRite Electronic Walkway Measurements & Definitions. http://wwwgaitritecom/Downloads/GAITRite_Measurement_Definitionspdf2006. Accessed May 4, 2010.
26. Hollman JH, McDade EM, Petersen RC. Normative spatiotemporal gait parameters in older adults. *Gait Posture*. 2011;34:111–118.
27. Abellan van Kan G, Rolland Y, Andrieu S, et al. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *J Nutr Health Aging*. 2009;13:881–889.
28. Hageman P. Gait characteristics of healthy elderly: a literature review. *Issues Aging*. 1995;18:14–18.
29. Srikanth V, Saling MS, Thrift AG. Vascular cognitive impairment. In: Gilman S, ed. *Neurobiology of Disease*. Burlington, MA: Elsevier; 2007:223–233.
30. Lezak MD. *Neuropsychological Assessment*. 3rd ed. New York: Oxford University Press; 1995.
31. Spreen O, Strauss E. *A Compendium of Neuropsychological Tests. Administration, Norms, and Commentary*. 2nd ed. New York: Oxford University Press; 1998.
32. Weschler D. *Weschler Adult Intelligence Scale*. New York: Psychological Corporation; 1997.
33. Yesavage J, Brink T, Rose T, Lum O, Huang V, Adey M, Leirer VO. Development and validation of a geriatric depression screening scale: a preliminary report. *J Psychiatr Res.* 1982–1983;17:37–49.
34. Martin K, Thomson R, Blizzard L, Wood A, Garry M, Srikanth V. Visuospatial ability and memory are associated with falls risk in older people: a population-based study. *Dement Geriatr Cogn Disord*. 2009;27:451–457.

35. Thomson G. *The Factorial Analysis of Human ability*. London: University of London Press; 1946.
36. Hollman JH, Childs KB, McNeil ML, Mueller AC, Quilter CM, Youdas JW. Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. *Gait Posture*. 2010;32:23–28.
37. Al-Yahya E, Dawes H, Smith L, Dennis A, Howells K, Cockburn J. Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev*. 2011;35:715–728.
38. Hausdorff JM. Gait variability: methods, modeling and meaning. *J Neuroeng Rehabil*. 2005;2:19.
39. Dubost V, Annweiler C, Aminian K, Najafi B, Herrmann FR, Beauchet O. Stride-to-stride variability while enumerating animal names among healthy young adults: result of stride velocity or effect of attention-demanding task? *Gait Posture*. 2008;27:138–143.
40. Maki BE. Gait changes in older adults: predictors of falls or indicators of fear. *J Am Geriatr Soc*. 1997;45:313–320.
41. Callisaya ML, Blizzard L, McGinley JL, Schmidt MD, Srikanth VK. Sensorimotor factors affecting gait variability in older people–a population-based study. *J Gerontol A Biol Sci Med Sci*. 2010;65:386–392.
42. Kerr B, Condon SM, McDonald LA. Cognitive spatial processing and the regulation of posture. *J Exp Psychol Hum Percept Perform*. 1985;11:617–622.
43. Maylor EA, Wing AM. Age differences in postural stability are increased by additional cognitive demands. *J Gerontol B Psychol Sci Soc Sci*. 1996;51:P143–P154.
44. Beauchet O, Allali G, Berrut G, Hommet C, Dubost V, Assal F. Gait analysis in demented subjects: interests and perspectives. *Neuropsychiatr Dis Treat*. 2008;4:155–160.
45. Camicioli R, Howieson D, Lehman S, Kaye J. Talking while walking: the effect of a dual task in aging and Alzheimer's disease. *Neurology*. 1997;48:955–958.
46. Segev-Jacubovski O, Herman T, Yogev-Seligmann G, Mirelman A, Giladi N, Hausdorff JM. The interplay between gait, falls and cognition: Can cognitive therapy reduce fall risk? *Expert Rev Neurother*. 2011;11:1057–1075.
47. Gauthier S, Reisberg B, Zaudig M, et al. Mild cognitive impairment. *Lancet*. 2006;367:1262–1270.