Research Article

Longitudinal Relationships Between Cognitive Decline and Gait Slowing: The Tasmanian Study of Cognition and Gait

Michele L. Callisaya, Christopher L. Blizzard, Amanda G. Wood, Amanda G. Thrift, Tracey Wardill, and Velandai K. Srikanth

1Stroke and Aging Research Group, Department of Medicine, Southern Clinical School, Monash University, Clayton, Victoria, Australia. 2Menzies Research Institute Tasmania, University of Tasmania, Hobart, Australia. 3School of Psychology, University of Birmingham, Edgbaston, UK. 4Florey Neuroscience Institutes, Heidelberg, Victoria, Australia. 5Melbourne Neuropsychology Services, East Melbourne, Victoria, Australia.

Address correspondence to Michele Callisaya, PhD, Southern Clinical School, Monash Medical Centre, Level 5, Block E, 246 Clayton Road, Clayton, Victoria 3168, Australia. Email: michele.callisaya@monash.edu

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Abstract

Background. Gait slowing and cognitive decline are both common in older people. Although cross-sectionally related, the longitudinal associations between specific cognitive functions and gait speed are less well understood. We aimed to determine whether decline in specific cognitive domains are associated with change in gait speed.

Methods. Participants aged 60–85, randomly selected from the electoral roll, were assessed twice over 3 years. Gait speed was obtained using the GAITRite walkway. Raw scores from a cognitive battery were subjected to principal component analyses deriving summary domains of executive function, processing speed, memory, and visuospatial ability. Multivariable linear regression was used to examine the associations between change in each cognitive domain and change in gait speed, adjusting for covariates and stratifying for the presence of baseline cognitive impairment.

Results. Mean age at baseline was 71.1 years (SD = 6.7) and 56% (159/284) were men. Mean follow-up was 2.55 (0.47) years. Decline in executive function, but not other cognitive domains (p > .05), was associated with decline in gait speed, cm/s (β = −3.55, 95% CI = −5.49, −1.61; p < .001), both in the presence and absence of baseline cognitive impairment. Stronger associations were seen for those with baseline multiple domain cognitive impairment (β = −6.38, 95% CI = −12.49, −0.27) and nonamnestic single-domain cognitive impairment (β = −7.74, 95% CI = −14.76, −0.72).

Conclusion. Decline in nonamnestic function (specifically executive function) was associated with decline in gait speed irrespective of the presence of baseline cognitive impairment. Strategies to improve or maintain executive function may prevent gait slowing.

Key Words: Gait—Cognition—Executive function—Memory—Aging—Brain

Gait impairments occur in more than 30% of older people (1). Gait slowing has been linked to increased risk of falls, hospitalization, and need for increased care (2,3). Cognitive impairment also has an enormous impact on an older individual's quality of life, and, along with reduced mobility is one of the primary reasons for residential care. Interestingly, cognitive impairment and slow gait often occur...
together in older people. Results of cross-sectional studies of older people provide evidence that poorer executive function, attention, and processing speed are associated with slow gait (4–6). There are conflicting reports regarding the association of memory with gait speed (4,5), and there was no association found between visuospatial function and gait speed in one study, but this was based on a single test of visuospatial function (5). These results, and others from cross-sectional dual-tasking studies (7), suggest that gait may rely largely on executive function and attention particularly in older age (8), but that the evidence is less certain for memory and visuospatial function. Better evidence of a causal relationship may arise from longitudinal studies. Two such studies have been conducted to examine the relationship between change in global cognitive function and change in gait speed (9,10) with conflicting results. Decline in a global cognitive score was associated with gait slowing in one study of disability-free older people (10), but was not associated with gait in a clinical trial of oestrogen therapy in women (9). Differences in samples or the use of limited measures of global cognitive function may explain these conflicting results. Only two longitudinal studies, to our knowledge, have investigated the relationship between change in individual cognitive domains and change in gait speed (11) or a composite mobility score (12). But in the second study, the strength of associations with each individual cognitive test was not reported (12). Examining the longitudinal associations between individual cognitive domains and gait speed can assist in developing appropriate cognitive strategies and treatments to prevent gait slowing in older people.

The aim of this study was to examine the longitudinal associations between change in a number of cognitive domains and change in gait speed. Based on prior cross-sectional data, the primary hypothesis was that change in executive function and processing speed, but not memory or visuospatial function, would be associated with change in gait speed. A secondary hypothesis was that the associations would vary according to the presence of baseline cognitive impairment, as others have reported the protective effects of cognition on decline in gait speed are stronger in those with higher cognitive reserve (13).

### Methods

#### Participants

We randomly selected participants aged between 60 and 85 from the Southern Tasmanian electoral roll, into the Tasmanian Study of Cognition and Gait (TASCOG). Participants were excluded if they lived in a nursing home, had a history of Parkinson's disease, or had any contraindication to magnetic resonance imaging scan (as magnetic resonance imaging was a requisite in the larger study). Participants also needed to be able to walk unaided. Methods of recruitment have been reported previously (14). Baseline measurements occurred between January 2005 and December 2008, and follow-up measurements occurred between March 2008 and March 2010 using identical methods. The Southern Tasmanian Health and Medical Human Research Ethics Committee approved this study and written consent was obtained from all participants.

#### Gait Measurement

At baseline and follow-up, participants completed six walks at their preferred walking speed over the 4.6-m computerized GaitRite walkway (CIR Systems). Participants started 2 m before and finished 2 m after the mat. Gait speed (cm/s) was averaged over the six walks. The GaitRite has excellent test–retest reliability in older people (15).

### Cognitive Function

At baseline and follow-up, a battery of cognitive tests was administered to assess the following four cognitive domains: (i) Executive function—using the Controlled Word Association Test (COWAT, using the letters F, A, and S) (16); (ii) Visuospatial ability—using the Rey Complex Figure copy task (16); and (iv) Memory—using the Hopkins Verbal Learning Test—Revised (total immediate recall, delayed recall, and recognition memory) (16) and a delayed reproduction after 20 minutes of the Rey Complex Figure (16). Based on test performance, a diagnosis of cognitive impairment at baseline was made if the participant scored ≤1.5 SD of age-, sex-, and education-appropriate norms in at least one test of each domain. Two clinical neuropsychologists reached consensus on the appropriate norms to use for our Australian population (ie, Stroop Color/Word Interference Norms (19); Rey Complex Figure norms (20,21); Hopkins Verbal Learning Test norms (22), Animal fluency norms and COWAT norms (23)). In each case, raw scores were converted to Z scores for each individual using age, education, and sex specific values, wherever appropriate. For Wechsler Adult Intelligence Scale-III subtests where the scaled score equivalent of ≤1.5 SD is 5.5, we adopted the conservative approach where a score of 5 was considered abnormal, rather than round up and use 6 as the cutoff. Rey Complex Figure recall was considered abnormal only if the baseline copy score was within normative limits. This conservative approach protects against likely false-positive impairments in visual memory performance based on a quantitative score alone; poor recall is unsurprising if the initial copy is impoverished. We adopted this approach after carefully considering visual inspection/expert judgement of all copy images but agreed that a more objective approach was most appropriate. Participants were classified as having cognitive impairment if any one domain was impaired.

### Other Measures

History of vascular risk factors such as hypertension, hypercholesterolemia, ischemic heart disease, smoking history, diabetes mellitus, and stroke was obtained using a standardized questionnaire. Mood was assessed using the Geriatric Depression Scale (24). Use of psychoactive or blood pressure lowering medications were also recorded. Body mass index was calculated using measures of weight and height.

### Statistical Analysis

Similar to our previous work (25), the raw scores of each cognitive test were grouped a priori into the specific cognitive domains (as described previously) of executive function, processing speed/attention, and memory. A principal component analysis was run on each of the four groups separately. Given the nature of the test groupings, only a single component was derived for each domain. Standardized regression scores for each of these components were derived for each individual using Thomson’s method (26)—and these scores were used in analyses. For visuospatial function, only the raw score of the Rey Complex Figure was used (not needing principal component analysis). To calculate follow-up scores for the domains of executive function, processing speed/attention and memory, standard scores were determined for participants’ phase two cognitive test scores so that they were on the same scale as phase one tests. They were then

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multiplied by the phase one factor loading scores and then summed to get scores for each domain. Change scores in gait speed and each cognitive domain were derived by calculating the difference between variables at the two time points (variable at follow-up—variable at baseline) for each individual.

Two-sample t-tests and chi-square tests were used to compare characteristics between participants with complete follow-up and those who were lost to follow-up. Among those who had follow-up data, gait speed and cognitive variables were compared between baseline and follow-up using a paired t-test. Multivariable linear regression was then used to examine the association between change in the individual cognitive domain scores (independent variable) and change in gait speed (dependent variable), adjusting initially for age, sex, and elapsed time. We further adjusted for baseline measures of self-reported medical history and gait speed only if the inclusion of the relevant variable changed the coefficient of the exposure variable by more than 10% (27). In secondary analyses, we then stratified by the presence or absence of any cognitive impairment at baseline to determine its effect on associations. When the associations in strata (the presence or absence of cognitive impairment) were significant (p < .05), we performed further analyses to explore the impact of stratiﬁng by single or multiple cognitive impairment, and also the type of impairment (amnestic or nonamnestic). To account for the possibility that the findings may have been biased from losses to follow-up, we repeated analysis using inverse propensity weighting (28). Regression models controlling for baseline information that was signiﬁcantly different between those with data at both time points and those lost to follow-up (Table 1) were used to estimate the probability of response. The reciprocals of these propensities were used as weights in the analysis. The reciprocal of the probability of response was used as weights in the analysis. The reciprocal of the probability of response was used as weights in the analysis. The reciprocal of the probability of response was used as weights in the analysis. The reciprocal of the probability of response was used as weights in the analysis.

Results

From the baseline sample (n = 429), we excluded participants with missing gait (n = 9) or cognitive data (n = 4), leaving 416 participants. At follow-up, 284/416 (68.3%) participants had both gait and cognitive data (Figure 1). Compared with those who were followed-up, those lost to follow-up (n = 132) were more likely to be older (p < .001), with a baseline history of ischemic heart disease (p = 0.01), stroke (p = 0.001) and lower mood (p < .001), be on blood pressure lowering medication (p = .02), be cognitively impaired (p = .001), and walk more slowly (p < .001) (Table 1). The mean baseline age of those followed-up was 71.0 (SD = 6.7) years, and 56.0% (159/290) were men. The mean time between appointments was 30.8 (SD = 5.6) months. At baseline, 18.7% (53/284) had one cognitive impairment and 5.6% (16/284) had multiple cognitive domains impaired. Gait speed, cm/sec (p < .001) and cognitive domain scores (p < .001 for all) declined over the follow-up period (Table 2).

Table 1 presents the results of the regression analyses of the associations between change in each cognitive domain and change in gait speed, initially adjusted by age, sex, and elapsed time (model 1), and the final model (model 2) further adjusted for body mass index, mood, diabetes mellitus, stroke, and baseline gait speed. Other covariates did not change the β coefficient of cognitive variables by >10% and were therefore not included. A squared term of each cognitive variable was assessed in the model but was not significant. In the final model, decline in executive function (β = −3.54, 95% CI = −5.49, −1.60; p < .001), but not other domains, was significantly associated with decline in gait speed. Repeating analyses with only participants who had follow-up data on all cognitive domains (n = 276) did not substantially alter the results. In propensity-weighted analysis for nonresponse bias, this association was largely unchanged (β = −3.69, 95% CI = −5.21, −2.17; p < .001). The association was only slightly stronger in those with any baseline cognitive impairment (β = −3.79, 95% CI = −6.69, −0.90; p = .01) than in those without cognitive impairment (β = −3.20, 95% CI = −6.09, −0.31; p = .03), (p = .95 for interaction). In propensity-weighted analysis, the association strengthened in those with cognitive impairment (β = −3.93, 95% CI = −6.41, −1.45; p = .002) and weakened in those without cognitive impairment at baseline (β = −2.9, 95% CI = −5.16, −0.65; p = .01), (p = .78 for interaction).

We further explored the association between executive decline and gait slowing stratiﬁng by number and type of cognitive impairments. Memory was the most commonly affected domain (28/53). The change in executive function was 0.24 (SD = 0.67) for those with no cognitive impairment, 0.14 (SD = 0.83) for those with single-domain cognitive impairment and 0.48 (SD = 1.87) for those with multiple-domain cognitive impairment. The change in executive function was 0.24 (SD = 0.67) for those with no cognitive impairment, 0.14 (SD = 0.83) for those with single-domain cognitive impairment and 0.48 (SD = 1.87) for those with multiple-domain cognitive impairment.

<table>
<thead>
<tr>
<th>Table 1. Baseline Characteristics of the Sample.</th>
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<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Age (y), mean, SD</td>
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<tr>
<td>Males, n, %</td>
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<tr>
<td>BMI, mean, SD</td>
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<tr>
<td>Education (y), mean, SD</td>
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<tr>
<td>Self-reported medical history, n, %</td>
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<tr>
<td>Hypertension</td>
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<tr>
<td>Ischemic heart disease</td>
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<tr>
<td>Hypercholesterolemia</td>
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<tr>
<td>Diabetes mellitus</td>
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<tr>
<td>Ever smoker</td>
</tr>
<tr>
<td>Stroke</td>
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<tr>
<td>Geriatric depression scale, mean, SD</td>
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<tr>
<td>Current use of psychoactive medications</td>
</tr>
<tr>
<td>Current use of BP lowering medications</td>
</tr>
<tr>
<td>Cognitive impairment</td>
</tr>
<tr>
<td>Gait speed, mean, SD</td>
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</tbody>
</table>

Note: BMI = body mass index; SD = standard deviation.
for those with multiple domain cognitive impairment. There was a linear trend ($p = .05$) for stronger associations between executive decline and gait slowing with each level of baseline cognitive impairment (Figure 2) no cognitive impairment $\beta = -3.20$, 95% CI = $-6.09$, $-0.31$; $p = .03$, $n = 211$; single-domain cognitive impairment $\beta = -3.84$, 95% CI = $-8.18$, 0.51, $p = .08$, $n = 53$; multiple domain cognitive impairment $\beta = -6.38$, 95% CI = $-12.49$, 0.27; $p = .04$, $n = 16$). For those with a single cognitive impairment there was a statistically significant association between executive decline and gait slowing in those with nonamnestic type impairment ($\beta = -7.74$, 95% CI = $-14.76$, $-0.72$; $p = .03$, $n = 25$), but not in those with amnestic-type impairment ($\beta = -4.17$, 95% CI = $-10.39$, 2.05; $p = .18$, $n = 28$).

### Discussion

We found longitudinal associations between cognitive decline and gait slowing in older people. Primarily, a decline in executive function, but not other cognitive domains, was independently associated with gait slowing over time. This association was observed even in the absence of baseline cognitive impairment. It appeared strongest in those with baseline multiple domain cognitive impairment, suggesting that such people may be most at risk of adverse mobility-related outcomes. In those with single-domain cognitive impairment, only those with nonamnestic deficits displayed the association.

This study has several strengths. First, in contrast to other studies, we report longitudinal associations between decline in specific cognitive domains and gait slowing. We used a population-based sample,
Table 3. Associations Between Change in Cognitive Function and Change in Gait Speed.

<table>
<thead>
<tr>
<th>Model</th>
<th>Δ Gait speed (cm/s)</th>
<th>n</th>
<th>β</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard Model</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Memory decline</td>
<td>280</td>
<td>-0.07</td>
<td>-1.50, 1.36</td>
</tr>
<tr>
<td></td>
<td>Executive function</td>
<td></td>
<td>0.04</td>
<td>-1.68, 1.77</td>
</tr>
<tr>
<td></td>
<td>Processing speed</td>
<td></td>
<td>-0.05</td>
<td>-2.81, 2.69</td>
</tr>
<tr>
<td></td>
<td>Error rate</td>
<td></td>
<td>0.08</td>
<td>-3.79</td>
</tr>
<tr>
<td>2</td>
<td>Model 1 adjusted for age and sex and elapsed time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Memory decline</td>
<td>212</td>
<td>-0.04</td>
<td>-1.68, 1.77</td>
</tr>
<tr>
<td></td>
<td>Executive function</td>
<td></td>
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<td>-1.68, 1.77</td>
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<td>Error rate</td>
<td></td>
<td>0.08</td>
<td>-3.79</td>
</tr>
<tr>
<td></td>
<td>Stratification by baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No cognitive impairment</td>
<td>212</td>
<td>-0.04</td>
<td>-1.68, 1.77</td>
</tr>
<tr>
<td></td>
<td>Any cognitive impairment</td>
<td></td>
<td>0.04</td>
<td>-1.68, 1.77</td>
</tr>
<tr>
<td></td>
<td>No cognitive impairment</td>
<td>212</td>
<td>-0.04</td>
<td>-1.68, 1.77</td>
</tr>
<tr>
<td></td>
<td>Any cognitive impairment</td>
<td></td>
<td>0.04</td>
<td>-1.68, 1.77</td>
</tr>
</tbody>
</table>

Note: Model 1 adjusted for age and sex, elapsed time. Model 2 adjusted for the same factors as Model 1 with the addition of BMI, depression, diabetes mellitus, stroke, and baseline gait speed. Significant findings are bolded.

Results of the few previous longitudinal studies of change in cognitive function and its association with gait slowing have been conflicting (9-11). In one study of disability-free older people (mean age 74.3 years, SD = 2.7) (10), the authors found that a decline in a global cognitive score (calculated by combining scores on a number of cognitive domains) was associated with gait slowing over 6 years. By contrast, in a clinical trial of women taking oestrogen therapy (mean age 70.3 years, SD = 3.7), no association was found between changes in Modified Mini-Mental State score and gait over 6 years (9). These conflicting results may reflect differences in sample type or the use of poorly sensitive global measures of cognition (9,10). Investigators of a further study (12) of older retirees (mean age 80.6 years, SD = 7.2 with impaired mobility and mean age 76.9 years, SD = 7.2 no mobility impairment) found that change in memory, perceptual speed, and visuospatial function were associated with change in a mobility score (number of steps and time taken to complete an 8-foot walk with a 360° turn, and standing on each leg for 10 seconds) over a mean of 4.5 years, although the strength of the individual association for each domain was not reported (12). Finally, in a population-based sample of older men and women (mean age 68.79 years, SD = 6.33), change in executive function and processing speed were associated with slower gait speed over 6 years (11). Our findings of an association that is restricted to executive decline may be explained by the use of more complex mobility tasks (12), the older sample (12) or differences in cognitive tests used in the previous studies that have examined specific cognitive domains (11,12). Our results are in agreement with most previous cross-sectional studies of associations between slower gait speed at usual pace and poorer executive function (4-6), and no association with memory (5,29) or visuospatial function (5). Taken together, current evidence suggests that executive function may have the most important role in maintaining walking speed. Executive function, as tested by the COWAT and Stroop tests, reflect several abilities including inhibiting a prepotent response, set shifting, response monitoring, and mental flexibility. It is not clear whether difficulties in these cognitive domains impacts on walking action or whether instead a common neural pathway underlies the impairments observed here.

A temporal relationship strengthens the evidence for a link between executive decline and gait slowing. However, the direction of association is still uncertain. A recent study eloquently showed that, in well-functioning older women measured six times over...
approximately 9 years, the direction of associations between cognitive function and gait speed were bidirectional (30). In our study, the association between executive decline and gait slowing persisted in the absence of baseline cognitive impairment, suggesting that gait slowing could be a marker for incipient cognitive decline, which may manifest clinically at a future stage. Indeed others have found impaired gait at baseline is associated with decline in global cognitive function (31) and dementia (32). In addition, we found the association between executive function and gait slowing was found in the presence of a nonamnestic (rather than amnestic) cognitive deficit. These are consistent with previous findings that gait abnormalities, such as slow gait and smaller steps, precede the diagnosis of non-Alzheimer’s dementia (33), of which some authors have suggested to be characterized by executive impairments (34).

Cerebrovascular disease (infarcts, white matter hyperintensities), particularly in subcortical locations, presents a plausible common cause for both executive and gait decline. Age-related white matter (35) and grey matter atrophy in areas important for executive function such as the prefrontal cortex (36–38), parietal, and subcortical areas have also been linked to slower gait. It is plausible that executive decline results in a decline in gait speed because an older person is less able to compensate for the impairments in sensorimotor function that contribute to gait decline (7), or has reduced ability to plan, monitor, adapt, and multitask while negotiating an environment. The stronger associations we found in those with multiple cognitive impairments may simply reflect the progression and severity of the underlying disease. Alternatively, a critical threshold may be reached where older people can no longer compensate for increasing impairment in cognitive function leading to a steeper decline in physical function. This is similar to recent findings where the protective effects of executive function against decline in gait speed were stronger in those with higher cognitive reserve (13). However, our stratified analyses are limited by small numbers of observations, and the results should be considered as hypothesis-generating, rather than definitive.

Our results have important clinical implications, suggesting that interventions aimed at preserving executive function may be important in preserving mobility in older age. Both aerobic and resistance-training exercises can improve executive function in older people (39,40), and may therefore prevent decline in gait speed. For those with slow gait, there is some preliminary evidence that a computerized cognitive remediation program can improve walking speed (41). Pharmacological agents, such as methylphenidate, designed to improve attention and possible executive function, may also improve gait (42).

In summary, we found that in an older population-based sample, decline in executive function was associated with a decline in gait speed. These results support further research into interventions targeted at preserving executive function in order to preserve mobility in older people.

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Conflict of Interest
There are no conflicts of interest.

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