Walking Speed, Processing Speed, and Dementia: A Population-Based Longitudinal Study

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Background. Slow walking speed has been shown to predict dementia. We investigated the relation of walking speed, processing speed, and their changes over time to dementia among older adults.

Methods. This study included 2,938 participants (age 60+ years) in the population-based Swedish National study on Aging and Care in Kungsholmen, Sweden, who were free from dementia and severe walking impairment at baseline. Walking speed was assessed with participants walking at their usual pace and processing speed was defined by a composite measure of standard tests (digit cancellation, trail making test-A, pattern comparison). Dementia at 3- and 6-year follow-ups was diagnosed according to Diagnostic and Statistical Manual of Mental Disorders-IV criteria.

Results. Of the 2,232 participants who were reassessed at least once, 226 developed dementia. Logistic regression models showed that each standard deviation slower baseline walking speed or decline in walking speed over time increased the likelihood of incident dementia (odds ratios 1.61, 95% confidence interval [CI] 1.31–1.98; and 2.58, 95% CI 2.12–3.14, respectively). Adjustment for processing speed attenuated these associations (odds ratios 1.26, 95% CI 1.01–1.58 and 1.76, 95% CI 1.33–2.34). Mixed-effects models revealed statistical interactions of time with dementia on change in walking and processing speed, such that those who developed dementia showed accelerated decline. At baseline, poorer performance in processing speed, but not in walking speed, was observed for persons who developed dementia during the study period.

Conclusions. Processing speed may play an important role for the association between walking speed and dementia. The slowing of walking speed appears to occur secondary to slowing of processing speed in the path leading to dementia.

Key Words: Aging—Dementia—Physical function—Walking speed—Processing speed.

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The steady increase in number of people with disability due to the aging of the population places growing demands on health care and social services. Dementia is the most common and devastating condition in older people and results in tremendous burdens to individuals, their families, and the health care system. A clinical diagnosis of dementia is usually preceded by many years of cognitive decline (1). To enable more successful preventive interventions, it is important to identify factors associated with the pathway to or the development of dementia.

Many large population-based studies have demonstrated associations of physical impairments and disability with future development of cognitive impairment and dementia (2–7). Performance-based measures, such as walking speed, may be more sensitive than self-reported measures in assessing these relationships (5). Other studies have found that cognitive impairment or decline in cognitive function may predict future physical impairments (8–11). These studies suggest that similar or shared degenerative processes may underlie a decline in motor and cognitive functions in aging (3).

Studies correlating changes in physical and cognitive functions are few but show significant relationships between changes in walking speed and global cognitive functioning (12,13). However, inconsistencies have been found in the temporal relation between decline in cognitive and physical functions in the aging process and in relation to dementia (3). A possible explanation to the inconsistent results regarding the temporality may be that different dimensions of physical and cognitive functioning are differently susceptible to age-related or pathological changes. Furthermore, it has been suggested that specific aspects of cognition are more particularly associated with physical function. For example, some studies have found walking speed to be more strongly associated with processing speed than with other measures of cognition (10,14,15). In addition, emerging evidence indicates that similar or shared degenerative processes in the central nervous system may
be important contributors to impairments in speed of both movement and mind (16–18). The association of walking speed, processing speed, and its changes over time with dementia among older adults has so far not been elucidated.

We hypothesized that people who developed dementia during the study time would show an accelerated decline in walking and processing speed and that the association of walking speed with incident dementia would be attenuated when controlling for processing speed. The purpose of this study was to verify these hypotheses using longitudinal data from a population-based study of older adults in central Stockholm, Sweden.

**Methods**

**Study Population**

We used longitudinal data from the Swedish National study on Aging and Care in Kungsholmen, which is one of four subprojects included in the Swedish National study on Aging and Care (19). The Swedish National study on Aging and Care in Kungsholmen study population consists of a sample of people aged 60 and older, living at home or in institution in the Kungsholmen district, a central area of Stockholm. The study used stratified sampling; the Kungsholmen population was first stratified by age, and then a random sample was selected from each age group. In total, 11 age cohorts were chosen with two different age intervals: 6-year intervals in the younger cohorts (60, 66, 72, and 78 years) and 3-year intervals in the older cohorts (81, 84, 87, 90, 93, 96, and 99+ years). Follow-up is performed every 6 years for younger cohorts (60–78 years) and every 3 years for older cohorts (age 78+ years). The baseline data collection was conducted during 2001–2004, the first follow-up for the older cohorts was conducted during 2004–2006 (3-year follow-up), and the second follow-up for the older cohorts and the first follow-up for the younger cohorts were completed in 2010 (6-year follow-up). At baseline, a total of 5,111 persons were selected for participation. Of these, 4,590 were alive and eligible to participate, and 3,363 (73.3%) participated in the baseline examination. Of those examined at baseline, 843 (25%) persons died before the 6-year follow-up, 462 (14%) did not participate in further examinations, and 2,058 (61%) participated at the 6-year follow-up. In the older cohorts, 1,581 persons were examined at baseline; of those, 437 (28%) died before the 3-year follow-up, 152 (9%) did not participate in further examinations, and 992 (63%) participated at the 3-year follow-up. We excluded persons who were unable to walk, had dementia, or had a score less than 24 on the Mini-Mental State Examination (20) at baseline. The analytical sample included 2,938 participants at baseline. Of those, 2,232 were reexamined on at least one follow-up occasion; 1,631 at one occasion (247 at the 3-year follow-up and 1,384 at the 6-year follow-up) and 601 at two occasions. Thus, the analytical sample at the 3- and 6-year follow-ups consisted of 848 and 1,985 participants, respectively (Figure 1). Compared with the excluded participants, the analytical sample was significantly younger (baseline mean age ± standard deviation [SD] 72.8 ± 10.3 vs 88.0 ± 8.3, p < .05), included fewer women (62.4% vs 81.1%, p < .05), and was better educated (for university education 35.6% vs 11.3%, p < .05).

The Swedish National study on Aging and Care in Kungsholmen study was approved by the Ethics Committee at Karolinska Institutet and by the Regional Ethical Review Board in Stockholm, Sweden. Written informed consent was collected from participants. If the person was cognitively impaired, a proxy was asked for consent.

**Data Collection**

Data were collected at our research center via interviews, clinical examinations, and testing by trained staff. Data on medical history were also available from the local inpatient register system. For those who agreed to participate but were unable to come to the research centre, home visits were conducted.

Walking speed was assessed by trained nurses, where the participants were requested to walk 2.4 or 6 m at a self-selected speed (21). The length of the walk was determined by asking the participants how fast they normally walk. Participants who rated themselves as fast or normal walkers did the longer walk and slow or very slow self-rated walkers did the shorter walk. The walking speed reflects the speed (m/s) from whichever walk was performed by the participant (22).

Processing speed was assessed by psychologists using three paper-and-pencil tests (23): The digit cancellation test (24) consisted of 11 rows of random numbers ranging from 1 to 9. Participants were instructed to sequentially go through the rows as quickly as possible and cross out every “4” they encountered. The score used for this task was the number of correctly crossed 4s within 30 seconds. The trail making test (25) consisted of 13 circles, and required participants to connect encircled numbers in numerical order (1, 2, 3, etc.). The trail making test was scored by how long time (in seconds) it took to complete 12 correct connections. The first mistake was corrected by the administrator and did not result in a lower score (correction time was not included in the completion time). In addition, participants were allowed to make one careless connection (>2 mm outside the circle). For the pattern comparison test (26), participants were presented with pairs of line segment patterns. They were asked to sequentially go through the patterns as rapidly as possible and mark whether the patterns were “same” or “different.” The task consisted of two pages with 30 patterns on each page. Participants were given 30 seconds per page and the test was scored as mean number of correct classifications across the two pages. Processing
speed was defined as the averaged normalized score of the above-mentioned tests. Specifically, the summary score was created by dividing the sum of the individual normalized scores by the number of tests.

Global cognitive function was assessed by physicians using the Mini-Mental State Examination (20).

Dementia was diagnosed by the examining physician according to the Diagnostic and Statistical Manual of Mental Disorders-IV criteria.

Covariates.—Data on age, gender, and education were derived from the nurse interview at baseline. Education was assessed as the number of years of formal schooling. Stroke was diagnosed at the baseline examination by the examining physicians based on clinical examination, self-reported medical history, and inpatient register information. Pain was assessed by the physicians at baseline by asking the participants whether they had experienced any pain during the past 4 weeks.

Data Analysis

We presented baseline characteristics using mean ± SD for continuous variables and frequency (%) for categorical variables. Statistical differences in baseline characteristics by dementia status at follow-up were examined using t test or chi-square test.

For the analyses of walking speed, processing speed, and global cognition, all measures were converted to normalized scores, using the baseline mean and SD as the standardization base. This was done to facilitate comparisons across different measures. Logistic regression analyses were conducted to estimate the odds ratio (OR) and 95% confidence interval (CI) of incident dementia associated with baseline levels and change in walking speed, processing speed, and global cognition over the study period. Change in speed or cognition was computed by subtracting the baseline score from the 6-year follow-up score (3-year follow-up score for those individuals who were only reexamined at the 3-year follow-up). All models were adjusted for age, gender,

Figure 1. Flow chart of the study participants in the total sample and by age (<78 vs 78+ years). NP = nonparticipants.
education, stroke, and pain. Analysis of change was additionally adjusted for years of follow-up.

In further analyses, changes in walking speed, processing speed, and global cognition across all three testing occasions (baseline, 3-year follow-up, and 6-year follow-up) were analyzed using linear mixed-effects models to estimate the change over the study period in relation to incident dementia. The within-person residual covariance matrix was evaluated with the unstructured correlation structure. Each model included the follow-up time, expressed as the three testing occasions as an indicator variable, baseline scores of walking speed, processing speed, or global cognition, age, sex, education, stroke, and pain. We first investigated the average change in walking and processing speed and global cognition over the study period. In a second model, to verify if people who developed dementia during the study period showed an accelerated decline compared with those who did not, we examined the average change in walking and processing speed and global cognition over the study period by dementia at follow-up. We included the interaction between incident dementia and follow-up time on change in walking speed, processing speed, and global cognition. Interactions were tested by including simultaneously the independent variables and their cross-product variables in the same model. Statistical analyses were performed with Stata, version 13 (StataCorp, College Station, TX).

Results

Of the 2,232 participants who were reexamined on at least one follow-up occasion, 226 (10.1%) were diagnosed to have developed dementia during the 6-year follow-up period; 112 participants were diagnosed at the 3-year and 114 at the 6-year examination. The baseline characteristics among all participants (n = 2,232) and by dementia status at follow-ups are shown in Table 1.

Logistic regression models showed that each SD slower baseline walking speed increased the likelihood of incident dementia (OR 1.61, 95% CI 1.31–1.98; Table 2). When further including baseline processing speed in the model, the association of walking speed with dementia was attenuated but remained significant (OR 1.26, 95% CI 1.01–1.58). The same pattern was observed, but to a lesser extent, when global cognition was included in the model (OR 1.45, 95% CI 1.17–1.80). Slower processing speed and worse global cognition at baseline were significantly associated with increased likelihood of incident dementia after adjusting for baseline walking speed (ORs 3.11, 95% CI 2.32–4.16; and 1.85, 95% CI 1.56–2.20, respectively). Further analysis showed that for each SD decline in walking speed over the study period, the likelihood of developing dementia was 2.58 (95% CI 2.12–3.14). After adjusting for processing speed or global cognitive function, this association was again attenuated but remained significant: 1.76 (95% CI 1.33–2.34) and 1.85 (95% CI 1.39–2.47), respectively. In addition, the increased likelihood of developing dementia by each SD decline in processing speed and global cognition over time were 5.47 (95% CI 3.59–8.32) and 3.83 (95% CI 3.13–4.69), respectively, when adjusting for change in walking speed.

The linear mixed-effects models revealed significant declines in walking speed, processing speed, and global cognition over the follow-up period (Model 1 in Table 3). There were significant interactions of follow-up time with incident dementia on decline in walking speed, processing speed, and global cognition (Model 2 in Table 3 and Figure 2: p values < .001). Participants who developed dementia showed accelerated decline compared with those who did not, even after controlling for baseline scores. At baseline, there was no significant difference in walking speed (p value = .276) among those who developed dementia compared with those who did not, whereas participants

Table 1. Baseline Characteristics of All Participants and by Dementia Status at Follow-ups

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Participants Reassessed at Least Once (n = 2,232)</th>
<th>Dementia Status at Follow-ups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean ± SD or %</td>
</tr>
<tr>
<td>Age (y)</td>
<td>2,232</td>
<td>72.0 ± 9.9</td>
</tr>
<tr>
<td>Women</td>
<td>1,414</td>
<td>63.4</td>
</tr>
<tr>
<td>Education (y)</td>
<td>2,093</td>
<td>12.4 ± 4.2</td>
</tr>
<tr>
<td>Stroke</td>
<td>87</td>
<td>3.9</td>
</tr>
<tr>
<td>Pain</td>
<td>799</td>
<td>36.1</td>
</tr>
<tr>
<td>Walking speed (m/s)</td>
<td>2,167</td>
<td>1.1 ± 0.4</td>
</tr>
<tr>
<td>Processing speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit cancellation test*</td>
<td>2,032</td>
<td>17.8 ± 4.1</td>
</tr>
<tr>
<td>Trail making test (s)</td>
<td>2,036</td>
<td>15.0 ± 12.1</td>
</tr>
<tr>
<td>Pattern comparison test†</td>
<td>2,027</td>
<td>14.3 ± 3.8</td>
</tr>
<tr>
<td>Global cognition (MMSE)</td>
<td>2,230</td>
<td>29.0 ± 1.2</td>
</tr>
</tbody>
</table>

Notes: MMSE = Mini-Mental State Examination; SD = standard deviation.
*Number of correctly crossed 4s in 30 s.
†Mean number of correct comparisons in 30 s of part 1 and 2.
who developed dementia performed at a lower level on the processing speed tasks and global cognition at baseline ($p$ values $<.001$).

**DISCUSSION**

In this large-scale population-based study of older adults, we found that slow walking speed at baseline and its decline over time were associated with increased risk of developing dementia and that this association was attenuated after controlling for processing speed. There were significant interactions of time with incident dementia on change in walking speed, processing speed, and global cognition, such that those who developed dementia showed accelerated decline. Finally, at baseline, we found more pronounced differences in processing speed than in walking speed when comparing persons who developed dementia with those who did not. Our results suggest that the association between walking speed and incident dementia may be partly explained by deficits in processing speed and that slowing of walking speed in participants who develop dementia may occur secondary to decline in processing speed.

Previous studies show walking speed and its changes over time to be predictive of cognitive impairment and dementia (2,3,5–7). This study extends previous research by suggesting that cognitive function, in particular processing speed, may partly mediate this association. When including processing speed in the models, the association of walking speed with incident dementia was more attenuated compared with when we included global cognition. A possible explanation to this finding may be that walking speed is more strongly associated with processing speed and executive function than with other measures of cognition, as has been suggested by other studies (10,14,15). A recent study however found that other components of executive function, such as the ability to monitor and sustain mental effort,
may be more closely related to gait than processing speed is. Further studies are needed to elucidate these associations (27). It should be noted that walking speed remained a significant predictor of dementia even after controlling for cognitive performance.

Our patterns of results do not support the hypothesis that slowing of walking speed precedes cognitive decline in the path leading to dementia but rather suggests that slowing of motor function may occur secondary to the slowing of processing speed. Our findings may have several possible explanations. First, it has been suggested that subsequent cases of dementia show accelerated decline first in fluid abilities, such as processing speed, and later in crystallized abilities (1). Thus, cognitive deficits in the processing speed domain may be expected to occur very early in the dementia process, before any other clinical signs are present.
Secondly, being slower in perceiving the environment may result in more cautious behaviors, including slower habitual walk, which would suggest a direct link between slowing of mind and slowing of motor function. Thirdly, it is possible that vascular lesions and degenerative changes in the brain may contribute to impairments in speed of both movement and mind (16–18). For example, cerebrovascular lesions in frontal and periventricular areas have been shown to be associated with slow walking speed in community-living elderly people and in participants with incipient dementia (28,29). These areas are also involved in information processing (17). It should however be pointed out that the participants in our study were only followed up at one or two occasions. Thus, we were not able to study the patterns of changes in walking and processing speed over time. We therefore could not verify to what extent changes in walking and processing speed are interrelated as an expression of similar or shared degenerative processes. Further longitudinal studies with more frequent follow-ups are needed to disentangle the complex relationship between domains of physical and cognitive functions in the dementia process. Our study has several strengths, including the longitudinal design and the large sample of community-based older people. Moreover, walking speed, processing speed, and global cognition were examined by qualified health care professionals and dementia was diagnosed by physicians using standardized protocols. Limitations of the study include that the processing speed tasks require a certain level of manual dexterity and therefore are not pure measures of cognitive speed. Thus, it is possible that the effect of manual dexterity on the processing speed tests may have confounded our results. To limit this potential confounding effect, future studies should adjust for manual dexterity. In addition, the use of different distances in the test of walking speed may be a potential limitation. However, data from the U.S. National Health and Nutrition Examination Survey showed that walking speed measured over the distances 2.4 and 6 m are comparable (30), supporting the view that tests for walking speed are generally considered highly reliable, regardless of the distance (21). We did not have information on the exact time for onset of dementia and, thus, significant proportions of the reported declines are likely to have taken place after the onset. Finally, we excluded persons who were unable to walk, had dementia, or scored less than 24 on the Mini-Mental State Examination at baseline. Although the exclusion may reduce some confounding, it constrains the generalizability of our results to quite high functioning cohorts of older adults.

In summary, this study suggests that processing speed may play an important role for the association of slow walking speed and its decline over time with incident dementia. However, walking speed remains a significant predictor of dementia even when taking into account processing speed. Finally, the slowing of walking speed appears to occur secondary to slowing of processing speed in the path leading to dementia. This study adds to our understanding of the complex relations between physical and cognitive functioning in late life and their relation to incipient dementia. Disentangling these relations can help clinicians improve early recognition of the need for intervention to prevent dementia as well as physical disability.

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**Conflict of Interest**

The authors have no conflict of interest.

**References**