A Cross-Sectional and Longitudinal Study of the Relationship Between Walking Speed and Cognitive Function in Community-Dwelling Elderly People

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Background. Previous reports have shown links between cognitive function and physical performance in the elderly population, but it is unclear whether some specific cognitive domains are more strongly associated with measures of physical function such as walking speed. We investigated cross-sectional and longitudinal relationships between performance in five cognitive tests and walking speed among community-dwelling elderly people in the Dijon center (France) of the Three-City Study.

Methods. At baseline, 3,769 participants aged 65–85 years had measurements of 6-m walking speed, global cognition (Mini-Mental State Examination), verbal fluency (Isaacs Set Test [IST]), psychomotor speed (Trail Making Test part A [TMT-A]), executive function (TMT part B), and memory (Benton Visual Retention Test). After a mean follow-up of 7 years, walking speed was again measured in 1,732 of these participants.

Results. In cross-sectional analyses, slower maximum walking speed (MWS) at baseline was significantly associated with poorer performance in each cognitive test. The association was stronger with TMT-A ($\beta$ [$SE$] = −.127 [0.014], $p < .0001$) and IST ($\beta$ [$SE$] = .120 [0.014], $p < .0001$) than with the other tests. Only TMT-A ($\beta$ [$SE$] = −.053 [0.021], $p = .01$) and IST ($\beta$ [$SE$] = .063 [0.022], $p = .004$) were associated with the degree of MWS decline over time.

Conclusions. This study shows both cross-sectional and longitudinal associations between cognition and walking speed among community-dwelling elderly people. Poorer verbal fluency and slower psychomotor speed were more specifically associated with slower baseline MWS and with a stronger decline in MWS over time.

Key Words: Walking speed—Cognitive function—Motor decline—Cohort study.

Several studies of the relationship between cognitive and motor performance have relied on measures of walking speed during complex or dual-task tests in which participants are asked to walk while performing an additional task simultaneously, such as talking or calculating. These studies showed that, both in healthy and in demented participants, poorer executive performances were associated with slower motor performances and that more challenging tasks had a stronger influence (1–6). However, as the dual-task methodology is not standardized—the choice of the second task varies across studies and some studies prioritize one task more than the other—comparisons across studies can be difficult.

Other studies based on simple walking speed have also reported cross-sectional associations between cognitive function and motor performance (7–9). However, most of these studies involved summary cognitive scores, tests of global cognition (as measured by the Mini-Mental State Examination [MMSE] or its modified version), or a limited number of cognitive tests. Thus, it is unclear whether some specific cognitive processes, and particularly executive function, are more strongly related to walking speed. Moreover, few longitudinal studies have examined the relationship between specific cognitive domains and the decline in motor performance (10,11). If specific aspects of cognition are indeed associated with walking speed, this could help to develop or target specific interventions intended to prevent or slow the associated decline in physical function. It would also help to identify the most appropriate tests to adjust for cognitive function in epidemiological studies of motor function.

We thus studied cross-sectional and longitudinal relationships between cognition and motor function in participants aged 65–85 years enrolled in the Three-City (3C) Study. We examined the relationship between walking speed and performance in several cognitive tests and studied whether specific aspects of cognition are more specifically associated with walking speed.

Methods

Subjects

The 3C cohort study is ongoing in three French cities (Bordeaux, Dijon, and Montpellier) and is designed to estimate the risk of dementia and cognitive impairment attributable to vascular factors (12). The data reported here were...
collected in Dijon where a substudy of motor function was conducted. Eligibility criteria included living in the city, being registered on electoral rolls in 1999, being 65 years or older, and not being institutionalized. The study protocol was approved by the Ethics Committee of Kremlin-Bicêtre University Hospital, and each participant signed an informed consent form.

Between 1999 and 2001, 4,931 individuals underwent a baseline examination. Follow-up visits have since taken place every 2 years. At baseline, participants aged 85 years or younger were invited to the study center, whereas older participants were seen at home. Walking speed was measured only in participants who visited the study center, that is, in participants not more than 85 years old. Walking speed was measured at the study center at baseline and at the fourth follow-up examination (after a mean follow-up of 7 years), hereafter referred to as the follow-up examination. Thus, the longitudinal analyses are based on the change in walking speed between the baseline and the follow-up visit.

Of the 4,931 individuals recruited at baseline, 4,399 were aged 85 years and younger and visited the study center. Of these, 3,878 (88%) had at least one walking speed measurement and completed the battery of cognitive tests. Relative to participants with complete data, participants with missing data for either walking speed \((n = 517)\) or cognitive function \((n = 7)\) were older, had a higher body mass index (BMI), were more likely to use non-steroidal anti-inflammatory drugs (NSAIDs) for joint pain, and were less likely to have osteoporosis. We excluded 109 additional participants who had one or more conditions strongly affecting motor or cognitive function (Parkinson’s disease, \(n = 46\); disabling stroke, \(n = 31\); hip fracture, \(n = 10\); dementia, \(n = 31\)). Thus, the baseline sample consisted of 3,769 persons (3,693 measures available for maximum walking speed [MWS] and 3,767 for usual walking speed). At follow-up, among the 3,693 participants whose MWS was measured at baseline, 352 had died, 446 were more than 85 years old, and 148 had developed one or more conditions affecting motor or cognitive function. As shown in Figure 1, MWS was measured at the last follow-up visit in 1,732 of the remaining 2,747 participants.

Cognitive Tests

Five cognitive tests, chosen because they covered several cognitive domains and were sensitive to aging, were administered at baseline by trained psychologists.

The Isaacs Set Test (IST) measures verbal fluency and verbal production speed. Participants are required to generate lists of words in four semantic categories. When shortened to 15 seconds, it includes a speed component that may explain its high sensitivity to changes at higher levels of cognition (13,14). The Trail Making Test (TMT) assesses several cognitive skills, including visual scanning, psychomotor speed, and executive function (15). It is a two-part paper-and-pencil task. In part A (TMT-A), participants draw a line connecting a series of numbers scattered across a page as quickly as possible, respecting the ascending numerical sequence. In part B (TMT-B), participants alternate connect numbers and letters in numerical and alphabetical order. The TMT-A assesses psychomotor speed, defined by the amount of time it takes a person to process a signal, prepare a response, and execute that response; it has been suggested that most age-related differences in cognition are due to a decrease in processing speed (16). The TMT-B measures executive function and requires more cognitive flexibility than the TMT-A (17,18). We calculated the time taken to make a correct connection on the TMT-A and TMT-B by dividing the time to complete each part by the number of correct connections (expressed in seconds per correct connection) (19). The Benton Visual Retention Test (BVRT) assesses immediate visual memory: A series of designs is presented for 10 seconds, and the participant is required to recognize each design among four possibilities (20). The MMSE is a 30-item questionnaire that assesses global cognitive abilities (21).

Walking Speed

Walking speed was measured over a 6-m course among participants aged 85 years or younger who visited the Dijon center. Participants were asked to walk at both their usual and maximum pace (without running) and were timed with a chronometer connected to two photoelectric cells placed at each extremity of the course. Walking speed was measured at the study center (not during home visits) at the baseline examination and the follow-up examination, both of which took place at the study center.

Similar relationships were observed between the cognitive test results and both maximal and usual walking speed. We focused on MWS because it showed more variability than usual walking speed \((SD, 0.31\) and 0.21, respectively). In addition, MWS requires additional physical effort and highlights differences in function and fitness.

Other Measurements

Sociodemographic and medical data were collected during home visits by trained psychologists. Participants were asked whether they were being treated for chronic illnesses such as Parkinson’s disease and osteoporosis. Diabetes mellitus was defined by glycemia of 126 mg/dL or higher or use of antidiabetic treatment (22). Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured, and hypertension was defined by SBP 160 mmHg or higher or DBP 95 mmHg or higher or by antihypertensive drug use (23). Depressive symptoms were evaluated with the Center for Epidemiological Studies-Depression scale (24). Smoker status was categorized as “never,” “former,” or “current”. Alcohol consumption was recorded as the stated number of drinks per week. BMI was computed from measured weight
and height. Information on four instrumental activities of daily living (IADL4) known to be strongly associated with cognition (use of the telephone, use of public transportation or a car, medication use, and money management) was collected (25); participants were considered autonomous if they could perform the four activities unassisted. Physical activity was assessed as the frequency of participation to outdoors activities (e.g., hiking, swimming). Use of psychotropic drugs (antidepressants, anxiolytics, benzodiazepines, hypnotics) and regular use of NSAIDs were also recorded.

Participants were screened for dementia, and a standardized clinical protocol was used to diagnose prevalent and incident dementia (12). Dementia was diagnosed and classified by local investigators based on Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV) criteria, with validation by a panel of independent neurologists.

**Statistical Analysis**

We excluded from our analyses participants with conditions that compromised motor function (Parkinson’s disease, dementia, hip fracture in the previous 2 years, disabling stroke).

Analysis of covariance and the chi-square tests were used to assess the relationship between potential confounders and MWS.

Linear regression was used to study the cross-sectional relationship between MWS and each cognitive test result at baseline. MWS was considered as the dependent variable; each cognitive test was considered as the independent variable and entered in models as a continuous variable. Better performance is indicated by higher IST, BVRT, and MMSE scores and lower TMT-A and TMT-B scores. Because neither MWS nor the cognitive test results were normally
distributed and because we wanted to compare the strength of the relationships between MWS and the different tests, we used z scores of log-transformed variables. Standardized regression coefficients and standards errors are reported.

In longitudinal analyses, we examined the annual rate of MWS change (difference between follow-up and baseline divided by the interval between the measures). This variable was considered as the outcome and its relationship with baseline cognitive performance was examined in linear models adjusted for baseline MWS and other confounders.

Two methods were used to assess whether certain cognitive tests were more specifically associated with MWS. First, five separate models were built for the five cognitive tests, and for both the cross-sectional and the longitudinal analyses: (i) because age, sex, education, and BMI are strong determinants of walking speed and/cognitive function (26–28), all models were initially adjusted for these covariates after checking that there were no significant interactions with the explanatory variables; (ii) multivariable analyses were performed by further adjusting for variables that were associated with motor and cognitive function (any of the cognitive tests) in the present study (cross-sectional analysis: hypertension, diabetes mellitus, depressive symptoms, use of NSAIDs and of psychotropic drugs, alcohol consumption, physical activity, and IADL4 autonomy; and longitudinal analysis: hypertension, depressive symptoms, diabetes mellitus, physical activity, and use of psychotropic drugs). Second, both for cross-sectional and for longitudinal analyses, we entered the five cognitive tests in the same model as explanatory variables; other confounders were also included and we used a backward selection procedure (a two-tailed p value of .10 was required to remain in the model) to determine which cognitive tests remained associated with MWS independently of the others. We checked that there were no colinearity issues with this approach by estimating the variance inflation factor.

All analyses were performed using SAS version 9.1 (SAS Institute Inc., Cary, NC).

RESULTS

Baseline characteristics of the participants and their association with MWS are shown in Table 1.

Table 2 shows the association between the cognitive test results and MWS. After adjustment for age, sex, education, and BMI, poorer performance in each cognitive test was associated with slower MWS (p < .0001 for all). The largest regression coefficients (β [SE]) were observed for IST (.154 [0.014]) and TMT-A (−.159 [0.014]). After additional adjustment for other confounders (use of psychotropic drugs, NSAIDs, alcohol consumption, hypertension, depressive symptoms, diabetes mellitus, physical activity, and IADL4 autonomy), the parameters’ estimates were attenuated but all cognitive tests remained associated with MWS (model 2, Table 2). When we included the five cognitive tests in the same model, only TMT-A, IST, and BRVT remained significantly associated with MWS (model 3, Table 2).

Figure 1 shows how participants were selected for longitudinal analyses. Participants for whom MWS values at follow-up were not available were older, less likely to be men, less educated, and had a higher baseline prevalence of vascular risk factors, a slower baseline MWS, and poorer baseline cognitive performances (results not shown). Among the baseline characteristics, faster MWS (p < .0001), female sex (p < .0001), older age (p < .0001), low educational level (p < .0001), higher BMI (p < .0001), diabetes mellitus (p = .002), depressive symptoms (p = .007), hypertension (p = .005), low physical activity level (p < .0001), and psychotropic drug use (p = .03) were associated with MWS decline.

After adjustment for confounders, only poor IST performance (β [SE] = .063 [0.022], p = .004) and poor TMT-A performance (β [SE] = −.053 [0.021], p = .01) were associated with MWS decline (model 2, Table 3). When the five cognitive tests were introduced in a multivariable model, the backward selection procedure identified IST and TMT-A as the only predictors of MWS decline (model 3, Table 3).

When the cognitive test results were categorized in quartiles, we observed a dose–effect association for all the tests in cross-sectional analyses but only for IST and TMT-A in longitudinal analyses (data not shown). Similar findings were observed when we assessed executive function using scores such as time on TMT-B minus time on TMT-A or time/correct connection on TMT-B minus time/correct connection on TMT-A (data not shown).

COMMENT

In a large sample of participants aged 65–85 years, poor performance in tests assessing psychomotor speed and verbal fluency was associated both with slower walking speed at baseline and with the degree of decline in walking speed over time. These associations were independent of age, sex, education, BMI, and other confounders.

Our findings are consistent with those of other cross-sectional studies showing an association between cognition and physical performance (1,2,7,29,30). However, we studied several cognitive domains simultaneously and found that two, verbal fluency and psychomotor speed, were more specifically associated with MWS. A study of the association between physical and cognitive functions also reported that walking speed was more strongly associated with the digital symbol substitution test, which measures psychomotor speed (31), than with a test of global cognition (Modified Mini-Mental State [3MS] Examination) (8).

Few prospective studies have examined the relationship between cognitive performances and motor decline (10,11,28,32–35), and even fewer have focused on specific cognitive domains. In the Italian Longitudinal Study.

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on Aging, motor performance was based on a summary score for six motor tasks, including normal walking speed on a 5-m course. The investigators did not specifically assess psychomotor speed or verbal fluency, but they did evaluate attention, global cognition, and memory and found that only impaired attention was associated with motor decline after 3 years (10). In contrast with the Health Aging and Body Composition (ABC) Study group (11), we found that global cognition did not predict motor decline. The psychometric properties of the tests used to assess global function may account for this discrepancy. Indeed, the 3MS Examination is superior to MMSE as a

Table 1. Baseline Characteristics of the Study Participants (N=3,769)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Overall</th>
<th>MWS ≤ 1.5 m/s* (N=2,066)</th>
<th>MWS &gt; 1.5 m/s* (N=1,627)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>73.5 (4.7)</td>
<td>74.4 (4.7)†</td>
<td>72.1 (4.2)</td>
</tr>
<tr>
<td>Male sex</td>
<td>38</td>
<td>24†</td>
<td>57</td>
</tr>
<tr>
<td>High education level (&gt;12 y)</td>
<td>36</td>
<td>29†</td>
<td>45</td>
</tr>
<tr>
<td>Alcohol consumption ≥13 drinks/wk</td>
<td>27</td>
<td>21†</td>
<td>35</td>
</tr>
<tr>
<td>Current smoker</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Depressive symptoms§</td>
<td>13</td>
<td>16†</td>
<td>9</td>
</tr>
<tr>
<td>Hypertension</td>
<td>63</td>
<td>67†</td>
<td>57</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>9</td>
<td>10†</td>
<td>9</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>21</td>
<td>26</td>
<td>14</td>
</tr>
<tr>
<td>Regular use of NSAIDs for joint pain</td>
<td>15</td>
<td>18†</td>
<td>11</td>
</tr>
<tr>
<td>Psychotropic drugs use</td>
<td>26</td>
<td>31†</td>
<td>18</td>
</tr>
<tr>
<td>IADL4 autonomy ‖</td>
<td>92</td>
<td>91†</td>
<td>95</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>25.7 (4.1)</td>
<td>26.1 (4.3)§</td>
<td>25.2 (3.5)</td>
</tr>
<tr>
<td>IST</td>
<td>33.7 (6.8)</td>
<td>32.4 (6.5)†</td>
<td>35.4 (6.7)</td>
</tr>
<tr>
<td>BVRT</td>
<td>11.4 (2.0)</td>
<td>11.1 (2.0)†</td>
<td>11.9 (1.9)</td>
</tr>
<tr>
<td>MMSE</td>
<td>27.4 (1.9)</td>
<td>27.3 (2.0)†</td>
<td>27.7 (1.7)</td>
</tr>
<tr>
<td>TMT-A, s/correct connection</td>
<td>2.30 (0.92)</td>
<td>2.44 (0.92)†</td>
<td>2.09 (0.87)</td>
</tr>
<tr>
<td>TMT-A, s‡</td>
<td>54.65 (21.02)</td>
<td>58.12 (21.48)†</td>
<td>49.70 (19.07)</td>
</tr>
<tr>
<td>TMT-B, s‖</td>
<td>7.31 (10.5)</td>
<td>8.13 (11.69)†</td>
<td>6.19 (8.52)</td>
</tr>
<tr>
<td>TMT-B, s¶</td>
<td>107.39 (46.10)</td>
<td>114.66 (47.47)†</td>
<td>97.43 (41.80)</td>
</tr>
<tr>
<td>Regular physical activity (≥2 times/wk)</td>
<td>11</td>
<td>7†</td>
<td>16</td>
</tr>
<tr>
<td>Usual walking speed, m/s</td>
<td>1.08 (0.21)</td>
<td>0.99 (0.17)†</td>
<td>1.21 (0.17)</td>
</tr>
<tr>
<td>MWS, m/s</td>
<td>1.53 (0.31)</td>
<td>1.32 (0.18)†</td>
<td>1.80 (0.21)</td>
</tr>
</tbody>
</table>

Notes: Data are mean (SD) or %. BMI = body mass index; BVRT = Benton Visual Retention Test; IADL4 = four instrumental activities of daily living; IST = Isaacs Set Test; MMSE = Mini-Mental State Examination; MWS = maximum walking speed; NSAIDs = non-steroidal anti-inflammatory drugs; TMT-A = Trail Making Test part A; TMT-B = Trail Making Test part B.

* We present the mean or percent of each characteristic by MWS dichotomized at its median. However, the relation between MWS and each variable was studied using linear regression models with MWS as the dependent variable (p values † <.001; ‡ <.05).

§ Defined as a Center for Epidemiological Studies-Depression score ≥17 for men or ≥23 for women.

‖ Ability to perform IADL4 without help (use of telephone, use of public transportation or car, medication use, management of money).

¶ For comparison with other studies, the mean time to perform the test is presented.

Table 2. Association Between Cognitive Performances and MWS

<table>
<thead>
<tr>
<th>Cognitive Performances</th>
<th>Standardized Beta Regression Coefficients*</th>
<th>Model 1†</th>
<th>Model 2‡</th>
<th>Model 3§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β (SE)</td>
<td>p</td>
<td>β (SE)</td>
<td>p</td>
</tr>
<tr>
<td>IST</td>
<td>.154 (0.014)</td>
<td>&lt;.0001</td>
<td>.120 (0.014)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>BVRT</td>
<td>.115 (0.014)</td>
<td>&lt;.0001</td>
<td>.091 (0.014)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>MMSE</td>
<td>.083 (0.014)</td>
<td>&lt;.0001</td>
<td>.054 (0.014)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>TMT-A, s</td>
<td>−.159 (0.014)</td>
<td>&lt;.0001</td>
<td>−.127 (0.014)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>TMT-B, s</td>
<td>−.102 (0.015)</td>
<td>&lt;.0001</td>
<td>−.073 (0.014)</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Notes: BMI = body mass index; BVRT = Benton Visual Retention Test; IST = Isaacs Set Test; MMSE = Mini-Mental State Examination; MWS = maximum walking speed; NSAIDs = non-steroidal anti-inflammatory drugs; TMT-A = Trail Making Test part A; TMT-B = Trail Making Test part B.

* Based on z scores of log-transformed MWS and cognitive tests. Cognitive tests are considered as continuous independent variables.

† Adjustment for age, sex, education, and BMI.

‡ Additional adjustment for use of psychotropic drugs, NSAIDs, alcohol drinking, hypertension, depressive symptoms, diabetes mellitus, IADL4 autonomy, physical activity.

§ All five cognitive tests were included in the model; variables retained in the model were those with a p value ≤.10 using a backward selection procedure. Variables retained in the final model were IST, TMT-A, BVRT, age, sex, education level, BMI, use of psychotropic drugs, NSAIDs, alcohol drinking, hypertension, depressive symptoms, IADL4 autonomy, and physical activity.

‖ Seconds per correct connection.
function (more reliable than self-reported performance), the evaluation of several cognitive domains, and the assessment of numerous confounders.

However, because the participants were not representative of the general population, our results must be interpreted with care. In addition, follow-up MWS measurements were missing for some participants. These participants were older, overall less healthy, and more impaired than those included in the analyses; however, we looked at the baseline relation between the walking speed and the cognitive tests in persons who had a second measure and in persons who had not, and we found that the association was independent of the availability of a follow-up measure of walking speed. Finally, as we only measured MWS at two time points, we were unable to determine whether walking speed declined at a constant rate between the baseline and the follow-up examinations.

**CONCLUSIONS**

This study shows a cross-sectional and longitudinal association between cognition and walking speed in community-dwelling elderly participants. Among the different cognitive domains evaluated, only psychomotor speed and verbal fluency were associated with the degree of decline in walking speed over time. These findings provide further evidence that specific aspects of cognition are more particularly
associated with walking speed. If confirmed by further longitudinal research, our results might prove useful for developing interventions (eg, psychomotor speed training) designed to halt or slow the motor decline associated with poor cognition.

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