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Gait speed under varied challenges and cognitive decline in older persons: a prospective study

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Abstract

Objective: to examine whether usual gait speed, fast gait speed or speed while walking with a cognitive or neuromuscular challenge predicts evolving cognitive decline over 3 years.
Design: prospective study.
Setting: population-based sample of community-dwelling older persons.
Participants: 660 older participants (age ≥65 years).
Measurements: usual gait speed, fastest gait speed, gait speed during 'walking-while-talking', depression, comorbidities, education, smoking and demographics were assessed at baseline. Cognition was evaluated at baseline and follow-up. A decline in MMSE score by ≥3 points was considered as significant cognitive decline (SCD).
Results: adjusting for confounders, only fast speed was associated with cognitive performance at 3-year follow-up. One hundred thirty-five participants had SCD over 3 years. Participants in the lowest quartile of usual speed or walking-while-talking speed were more likely to develop SCD. Conversely, participants in the third and fourth quartiles of fast speed were more likely to develop SCD. *J*-test showed that the model including fast speed quartiles as a regressor was significantly more predictive of SCD than the models with usual speed or walking-while-talking speed quartiles.
Conclusion: measuring fast gait speed in older persons may assist in identifying those at high risk of cognitive decline.

Keywords: *Elderly, cognition, gait speed, ageing, significant cognitive decline*

Introduction

Cross-sectional studies have shown associations between cognition and physical performance in older persons, suggesting that they are interrelated [1–3]. Very few studies have investigated whether physical performance predicts decline in cognition [4–6] and suggest that slower usual gait speed predicts accelerated cognitive decline in the oldest old [5]. However, many studies included only healthy elderly [4,5] or did not consider potential confounders other than cardiovascular risk factors [5,6]. It is also reported that poorer cognitive function predicts slower walking speed [7]. However, available evidence suggests that subtle changes in motor functions precede cognitive impairment [4]. Using data from a population-based study, we investigated whether gait speed is an independent predictor of cognitive decline over 3 years.

Walking at usual self-selected speed is an automated motor behaviour that requires limited cognitive resources [8]. Thus, gait speed under challenging conditions (either cognitively or physically challenging [1,3,8]) may predict cognitive decline better than performance in usual walking tasks. Indeed, in older individuals, rapid walking speed is a better correlate of cognitive function compared to usual walking speed [1]. Further, a cross-sectional association between executive function and gait variability is evident only after a cognitive challenge is added during walking [8,9]. Whether gait speed under different challenges independently predicts evolving cognitive decline is unknown. This information is clinically and theoretically important for developing simple

criteria for characterising and tracking cognitive function in older adults and for developing further insight into mechanisms that lead to parallel decline of physical and cognitive function in older individuals.

We hypothesised that compared to usual gait speed, gait speeds under a physical or a cognitive challenge will be stronger predictors of cognitive decline over time and those in the lower quartiles of the gait speed under a physical challenge or a cognitive challenge will be more likely to demonstrate significant cognitive decline.

Methods

Participants

The InCHIANTI study population is a representative sample of the population living in the Chianti countryside of Tuscany, Italy [10]. In 1998, 1,453 adults were randomly recruited from the population registry of the two study sites. Follow-up data were collected after 3 and 6 years. The protocol was approved by the ethical committee of the Italian National Institute of Research, and Care of Aging and participants signed on informed consent. From those who were initially recruited, 1,163 participants participated in the year-3 follow-up. Compared to those who attended the year-3 follow-up, those who did not attend were older ($P < 0.001$), had worse MMSE scores ($P < 0.001$) and had reported higher ADL ($P < 0.001$) and IADL ($P < 0.001$) disability at the initial recruitment. The present study used the year-3 (baseline for this study) and year-6 (follow-up for this study) data of older participants (age $\geq$65 years).

Outcome measures

Cognitive function

Cognitive function was evaluated by the Mini-Mental State Examination (MMSE) [11]. MMSE is a widely used tool for measuring global cognitive impairment across multiple domains (orientation, memory, concentration, language and praxis) with scores ranging between 0 and 30, higher scores indicating better cognition. A score <24 points indicates cognitive impairment. A decline $\geq$3 points over the 3-year follow-up was considered as a significant cognitive decline (SCD) [12,13].

Timed walk performance

Performance-based tests of lower extremity function were carried out in a clinical setting. Participants used their usual gait aids. Those who needed manual assistance for walking or used a walker were excluded. The starting location was marked with a coloured tape. The end of the walking path at the distance of 7 m was not marked, to prevent slowing in anticipation. The time to complete the walking task was measured using two photocells positioned at the start and end of the path.

Participants were asked to walk in three conditions: (i) self-selected usual speed, (ii) fastest possible speed and (iii) 'walking-while-talking', walking while reciting names of animals starting with a specific letter. The time to walk 7 m from the standing start was converted to gait speed (m/s) [14].

Potential confounders

Education was recorded as the number of years in a school. Depressive symptoms were assessed using the centre for epidemiological studies depression scale (CES-D) [15]. Visual acuity was evaluated with optimal correction using a chart designed for the InCHIANTI study (score range, 0–11) [16]. Comorbidity index was assessed as the total number of prevalent comorbidities (Parkinson's disease, stroke, diabetes, hypertension, congestive heart failure, myocardial infarction, peripheral arterial disease, chronic obstructive pulmonary diseases, hip or knee replacement and hip or knee pain) [17]. Smoking status was assessed by self-report (Pack-year = packs per day × years of smoking) [18]. Demographic factors included age, gender and body mass index (BMI).

Statistical analysis

Variables not normally distributed were $\log_{10}$ transformed in analyses. Missing values were <1% and were replaced by overall means. Participants were stratified according to baseline MMSE quartiles and comparisons across quartiles were performed using age- and sex-adjusted analyses of covariance or logistic regression, as appropriate.

Relationships between MMSE follow-up scores and covariates were assessed by a partial correlation adjusted for baseline MMSE. Next, the MMSE follow-up score was separately regressed on the three gait speeds. Baseline MMSE and covariates correlated with the MMSE follow-up score with a *P*-value <0.200 were included in the multiple linear regression analysis.

To avoid the assumption of linearity in risk assessment of SCD according to walking performance, each walking performance was divided into quartiles and binary logistic regression was performed separately for each walking task. The highest quartile (fourth) was the reference category. Odds ratios and confidence intervals were calculated for the remaining three quartiles after adjusting for baseline MMSE and covariates. *J*-tests [19] were used to compare these three fully adjusted non-nested binary logistic regression models. The 'null-hypothesis' tested in the *J*-test is that if model 1 contains the correct set of regressors, then additionally including the fitted values of model 2 should not provide significant improvement. However, if model 2 provides a better fit than model 1 alone, it can be concluded that model 1 does not contain the correct set of regressors [19].

Statistical analyses were performed using SPSS version 15.0 and the *J*-test function in the R-Project package (http://www.r-project.org). Data are presented as

Table 1. Subject characteristics for the entire study population according to baseline MMSE quartiles ($n = 660$)

Variable	Overall	Quartile I MMSE 28–30	Quartile II MMSE = 27	Quartile III MMSE 24–26	Quartile IV MMSE < 24	F or $\chi 2$ and P
Age (years)	74.6 (5.3)	72.6 (4.5)	74.6 (5.2)	74.7 (5.1)	76.3 (5.6)	14.112, <0.001
Sex [female (%)]	54.2	48.7	53.1	49.3	65.6	13.619, 0.003
BMI (kg/m$^{2)}$	26.50 (3.84)	26.47 (3.56)	26.20 (3.87)	26.57 (3.73)	26.62 (4.17)	0.520, 0.669[a],[b]
Years of education	5.8 (3.4)	8.6 (4.7)	6.1 (3.0)	5.2 (1.9)	4.1 (1.8)	60.415, <0.001[a]
CES-D score[c]	14.6 (8.2)	11.5 (6.4)	14.0 (8.7)	14.6 (7.8)	17.4(8.8)	10.293, <0.001[b]
Visual acuity	0.35 (0.12)	0.39 (0.11)	0.38 (0.09)	0.34 (0.12)	0.30 (0.11)	13.717, <0.001[a]
Co-morbidity index[d]	1.3 (1.2)	1.2 (1.2)	1.3 (1.1)	1.3 (1.2)	1.5 (1.3)	0.222, 0.881
Smoking (pack-year)	12.4 (19.8)	15.7 (21.4)	11.6 (17.3)	13.4 (20.2)	8.9 (18.9)	1.560, 0.198[a]
Walking performance						
Usual speed (m/s)	1.23 (0.26)	1.36 (0.22)	1.22 (0.22)	1.22 (0.24)	1.13 (0.28)	11.796, <0.001[a,b]
Fast speed (m/s)	1.49 (0.33)	1.66 (0.29)	1.46 (0.26)	1.48 (0.33)	1.35 (0.34)	15.190, <0.001[a,b]
Walking-while-talking speed (m/s)	0.98 (0.28)	1.07 (0.26)	1.01 (0.25)	0.99 (0.29)	0.90 (0.27)	1.604, 0.187[a,b]

[a]age significant covariate; [b]sex significant covariate; [c]centre for Epidemiological Studies Depression scale score; [d]total number of the following conditions: Parkinson's disease, stroke, diabetes, hypertension, congestive heart failure, myocardial infarction, peripheral arterial disease, chronic obstructive pulmonary diseases, hip or knee replacement and hip or knee pain.

Table 2. Multiple linear regression analysis models relating the baseline walking speed in the three conditions and MMSE scores at 3-year follow-up ($n = 584$).

	Model 1			Model 2			Model 3		
Walking speed	β (SE)	t	P	β (SE)	t	P	β (SE)	t	P
Usual speed	0.068 (0.017)	4.079	<0.001	0.055 (0.021)	2.611	0.009	0.034 (0.020)	1.698	0.072
Fast speed	0.056 (0.013)	4.194	<0.001	0.057 (0.017)	3.338	0.001	0.038 (0.016)	2.375	0.021
Walking-while-talking speed	0.048 (0.015)	3.172	0.002	0.028 (0.018)	1.547	0.122	0.020 (0.017)	1.161	0.246

Model 1, adjusted for the baseline MMSE score only; model 2, adjusted for age, sex, BMI, years of formal education, depressive symptoms, visual acuity only; model 3, adjusted for baseline MMSE score, age, sex, BMI, years of formal education, depressive symptoms, visual acuity.

means ± SD unless mentioned otherwise. A P-value <0.05 was considered for statistical significance.

Results

At baseline, 660 participants completed the cognitive assessment and walking tests (age: average 74.6 ± 5.3, range 65–93; women 54.2%). Their MMSE scores ranged between 14 and 30. Ten participants scored <18 and 124 participants scored <24 on MMSE. The mean usual gait speed was 1.23 ± 0.26 m/s. Fast speed was significantly higher (1.49 ± 0.33 m/s, $P < 0.001$) and 'walking-while-talking' speed was significantly lower than usual speed (0.98 ± 0.28 m/s, $P < 0.001$). Participants in lower MMSE quartiles were older and were more likely to be women (Table 1). Adjusting for age and sex, they had less education, more depressive symptoms, worse visual acuity and generally walked at slower speed (Table 1). Of the 660 participants, 76 did not attend year-6 assessment. Therefore, prospective analysis included 584 participants. Compared to the 584 participants evaluated at the follow-up, those who were not evaluated were older (77.1 ± 6.3 vs. 74.3 ± 5.1, $P < 0.001$) and adjusting for age, had worse baseline MMSE performance (26.2 ± 2.8 vs. 24.8 ± 3.6, $P = 0.004$).

Longitudinal analysis

Pack-year and Comorbidity index were not correlated with follow-up MMSE ($P > 0.200$) and were excluded from analysis. In linear regression analysis adjusted for baseline MMSE scores only, the gait speed in all three conditions significantly predicted cognitive performance over 3 years (Table 2, model 1). In the fully adjusted model, only fast speed was a significant predictor of cognitive performance over 3 years (Table 2, model 3). To understand whether the ability of walking speeds to predict cognitive decline is different in those who are cognitively impaired at baseline (MMSE < 24), MMSE at baseline was coded as <24 and ≥24, and an additional interaction term 'MMSE × walking speed' was introduced in the analysis. The interaction was not statistically significant under any of the three walking conditions (data not presented).

A total of 135 participants had SCD during the follow-up. Of these, one participant had a baseline MMSE score <18, 31 had scores between 18 and 23, 42 had between 24 and 26 and 61 had a baseline MMSE score ≥27. Compared to those in the fourth quartile, participants in the second and first gait speed quartiles in all three walking conditions were significantly more likely to develop SCD during the 3-year follow-up (Table 3, model 1). In the fully adjusted model, only participants in the lowest quartile (first) of usual and

Table 3. Logistic regression models assessing the risk of developing the significant cognitive decline (decline in MMSE score ≥3) during the 3-year follow-up associated with lower quartiles of gait speed compared to the highest quartile in the respective walking condition ($n = 584$).

	Model 1		Model 2		Model 3	
Predictor variable	Odds ratio (CI)	*P*	Odds ratio (CI)	*P*	Odds ratio (CI)	*P*
Usual speed quartiles						
First 1.95–1.40 m/s	Reference		Reference		Reference	
Second 1.39–1.26 m/s	1.505(0.783–2.895)	0.220	1.324(0.670–2.539)	0.434	1.322(0.676–2.583)	0.415
Third 1.25–1.09 m/s	2.591(1.413–4.752)	0.002	2.034(1.051–3.934)	0.049	1.880(0.913–3.872)	0.086
Fourth <1.08 m/s	3.514(1.882–6.565)	<0.001	2.439(1.200–4.959)	0.014	2.316(1.152–4.898)	0.019
Fast speed quartiles						
First 2.67–1.70 m/s	Reference		Reference		Reference	
Second 1.69–1.50 m/s	1.463(0.745–2.873)	0.269	1.351(0.653–2.648)	0.342	1.350(0.667–2.731)	0.404
Third 1.49–1.30 m/s	3.054(1.633–5.715)	<0.001	2.629(1.324–5.222)	0.006	2.714(1.348–5.463)	0.005
Fourth <1.30 m/s	4.024(2.128–7.610)	<0.001	3.604(1.468–6.397)	0.002	3.168(1.503–6.676)	0.002
Walking-while- talking speed quartiles						
First 1.85–1.19 m/s	Reference		Reference		Reference	
Second 1.18–1.01 m/s	1.727(0.922–3.232)	0.088	1.551(0.765–2.754)	0.245	1.461(0.767–2.785)	0.249
Third 1.00–0.82 m/s	2.563(1.399–4.693)	0.002	1.793(0.926–3.472)	0.083	1.746(0.891–3.421)	0.104
Fourth <0.81 m/s	2.681(1.457–4.933)	0.002	2.109(1.124–3.924)	0.021	2.082(1.103–3.930)	0.024

Model 1, adjusted for baseline MMSE score; model 2, adjusted for age, sex, BMI, years of formal education, depressive symptoms, visual acuity only; model 3, adjusted for baseline MMSE score, age, sex, BMI, years of formal education, depressive symptoms, visual acuity.

'walking-while-talking' speed were significantly more likely to develop SCD. In contrast, even in the fully adjusted model participants in the second as well as first quartile of fast speed were significantly more likely to develop SCD (Table 3, model 3).

The results of the *J*-tests showed that the inclusion of the fitted values of the model with fast speed quartiles into the set of regressors of the model with usual speed quartiles provided significant improvement (estimate = 1.053 ± 0.400, $t = 2.631$, $P = 0.009$) for predicting SCD. However, the reverse test i.e. the inclusion of the fitted values of the model with usual speed quartiles into the set of regressors of the model with fast speed quartiles did not improve prediction (estimate = -0.110 ± 0.619, $t = -0.178$, $P = 0.858$). The fast speed model was significantly better than the 'walking-while-talking' model as well (estimate = 0.945 ± 0.311, $t = 3.031$, $P = 0.002$). There was no statistical difference between the models of usual speed and 'walking-while-talking' speed (estimate = 0.818 ± 0.496, $t = 1.648$, $P = 0.099$).

Discussion

This study investigated whether performance in walking tests in challenging conditions is stronger predictors of cognitive decline over time compared to performance in usual speed test. After adjusting for baseline MMSE scores and other potential confounders, performance in only the fast walking test remained significant independent predictor of accelerated decline of MMSE score over 3 years. Compared to the first quartile, the participants in the lower quartiles of the walking speeds were more likely to develop SCD over 3 years.

Although in younger individuals, walking is normally an automatic task, the cognitive and conscious component of gait control becomes progressively more important with ageing, possibly to compensate for sensory-motor deficits [20,21]. Paradoxically, however, decline in both cognitive and physical function is common in older adults. The interrelated decline of cognition and mobility is postulated to be due to underlying shared neural substrates [22–24]. For example, neuroimaging studies have shown that gait and mobility deficits are frequently encountered in older subjects with atrophy of temporal lobe [22] and prefrontal area [23]. Additionally, both global cognition and gait speed have been associated with atrophy of corpus callosum [24]. Available evidence [4,5] shows that slowing of usual gait speed often precedes the clinical emergence of cognitive impairment and suggests that usual gait speed can be a good predictor of impaired cognition in future. Our findings are only partially supportive of these conclusions. In the fully adjusted linear regression model, usual gait speed was only a borderline predictor, whereas fast walking speed was a significant independent predictor of an accelerated cognitive decline over 3 years. Further, the results of binary logistic regression analyses and subsequent *J*-tests suggest that compared to the models with usual or 'walking-while-talking' speed quartiles, the model with fast speed quartiles contains a more appropriate set of regressors and is, therefore, a better model to predict the likelihood of SCD. These findings are in line with the cross-sectional study of Fitzpatrick *et al.* [1]. It is postulated that fast walking being a more demanding task, allows identification of older persons with extreme functional level and physiologic reserve [1]. It is also possible that the higher demands imposed on the overall balance control systems during fast walking necessitate a much higher conscious control and cortical activity in older

individuals than that required for usual walking. Therefore, the maintenance of good performance in the fast walking task is closely related to the conservation of cortical function integrity which is also associated with good cognition.

Contrary to our initial hypothesis, performance in a walking-while-talking condition was the worst predictor of cognitive decline in every analysis. Possibly, when an additional challenge incorporates a secondary cognitive task, the cognitive resources are divided rather than causing a direct increase in cognitive demands of the primary walking task. Such a challenge may induce an interference with the walking task, and therefore, may primarily determine cognitive flexibility, which is associated with the ability to shift attention [25]. Coppin *et al.* [3] have reported that the average gait speed in the tertiles of executive function is not different when performing a cognitive secondary task. Thus, adding a challenge while walking that competes for attentional resources probably taps into a different domain of cognition and is not strongly related to cognitive capacity.

The results of our study are important for two reasons. First, it is a population-based study that provides evidence that in an older population, poor performance on a simple test of fast walking is an independent predictor of accelerated decline in global cognitive capacity. Further, this relationship sustains in those who are already impaired and in those who are cognitively intact at the baseline. Second, the results suggest that compared to usual walking speed, adding a neuromuscular challenge, but not a cognitive challenge, while walking may provide a more sensitive predictor of accelerated cognitive decline over time. Particularly, the likelihood for developing SCD is more than three times if the fast walking speed is <1.3 m/s. Future studies should develop a multivariate model that includes the measure of fast walking speed, to further refine prediction of clinically relevant decline in cognitive performance.

Certain limitations of this study should be noted. It is possible that clinically relevant SCD could vary at low or high initial MMSE scores. Future studies should investigate this highly important aspect. However, for standardisation in this study, (i) we used information from previous literature evidence and (ii) we examined the distribution of the change in the MMSE score over 3 years (Δ) in our study. The highest quartile denoted the change of ≥ 3. Further, our results can only speculate about a possible relationship between the 'walking-while-talking' performance and cognitive flexibility as we did not have a direct measure of this domain on cognition. Further, our population primarily comprised Caucasian older people living in small towns with low level of education, and therefore, may not completely represent a racially mixed highly educated older cohort living in metro/city areas.

In conclusion, in this population-based older cohort, the speed in fast walking condition, but not in usual pace or walking-while-talking conditions, was a significant independent predictor of accelerated cognitive decline over 3 years. In addition, older persons whose fast gait speed was <1.3 m/s were three times more likely to develop SCD over 3 years. A routine measurement of fast gait speed in older people may assist in identifying older persons who may need specific consideration for monitoring and exercising their cognitive function.

Key points

- Cross-sectional studies have shown associations between cognition and physical performance in older persons, but: Is there an association with change in cognition over time?
- Fast gait speed, but not the usual gait speed or gait speed in 'walking-while-talking' condition, was an independent predictor of accelerated decline of the MMSE score over 3 years.
- The results suggest that compared to usual gait speed, adding a neuromuscular but not a cognitive challenge while walking may provide a more sensitive predictor of accelerated cognitive decline over time.

Conflicts of interest

No conflicts of interest.

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