Age and Ageing 2006; **35:** 619–624
doi:10.1093/ageing/afl107
Published by Oxford University Press on behalf of the British Geriatrics Society 2006

Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study

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Abstract

Background: previous studies have reported an association between cognitive function and physical performance, particularly among older adults.
Objective: to examine the association between executive function and performance difference on complex versus usual walking tasks in a sample of non-demented older adults.
Design: population-based epidemiological study of older people residing in the Chianti area (Tuscany, Italy).
Participants: 737 community-dwelling individuals aged 65 years and older.
Methods: gait speed (m/s) was measured during the performance of complex walking tasks (walking/talking, walking/picking-up an object, walking/carrying a large package, walking over obstacles, walking with a weighted vest) and reference walking tasks (7 m usual pace, 7 m fast pace and 60 m fast pace). Executive function was assessed using the Trail Making Test (TMT). Other measures included Mini-Mental State Examination (MMSE), sociodemographic characteristics and selected physiological impairments.
Results: gait speed for the selected reference and complex walk tasks was consistently lower among participants with poor executive function. Per cent decline in gait speed compared with the reference task differed by executive function for certain tasks (e.g. walking/obstacles: 30 versus 24% decline in low versus high executive function respectively, $P = 0.0006$) but not for others.
Conclusions: poor executive function is associated with measures of gait, including specific challenges. Overall, the results showed that the cost associated with the addition of a challenge to the basic walking task differs by executive function and the nature of the task. Further research is needed to determine whether improvement in executive function abilities translates to better performance on selected complex walking tasks.

Keywords: *executive function, older adults, physical performance, dual tasks, mobility, elderly*

Introduction

Walking ability and cognitive function are important determinants of independence and autonomy in later life. Previous research has shown the existence of an association between cognitive status and physical function among middle-aged and older adults [1–3]. Poor performance on cognitive tests has been consistently and independently associated with significant declines in physical performance and greater dependency on basic and instrumental activities of daily living [2, 4]. It has been suggested that cognitive function may have a significant role in subclinical changes in functional status, first by interfering with an individual's ability to accurately perceive and report his/her functional status and second through impairments in executive abilities that are relevant for the performance of complex and goal-oriented activities [5, 6].

Executive function is defined as a set of cognitive skills that are necessary to plan, monitor and execute a sequence of goal-directed complex actions [7]. Age-associated decrements in executive function have been extensively reported [6, 8]. Previous work has shown a significant association between executive abilities and self-reported measures of physical functioning, particularly the performance of activities of daily living [5–9]. Recent work from the InChianti study has shown that executive cognitive ability measured by Delta Trail Making Test (ΔTMT) (defined in Methods) is related to obstacle course gait speed but not usual gait speed after adjusting for Mini-Mental State Examination (MMSE) score and other variables [3].

Mobility, defined as the ability to walk safely and independently in one's environment, is a critical component of functional independence [10, 11]. Mobility during daily life requires the ability to walk in complex and unpredictable environments with different characteristics and multiple challenges such as uneven terrain, inadequate lighting, inclement weather and cluttered travel paths [11] Complex walking tasks reflecting the ability to adapt locomotor patterns to challenging tasks or environmental conditions demand sensorimotor adaptations to gait beyond those required for walking under low-challenge conditions [11, 12]. The purpose of this study was to assess the relationship of executive function and performance of complex walking tasks among a sample of community-dwelling older adults whose global cognitive function was intact. We hypothesised that physical performance on complex walking tasks would be affected by executive function level and that individuals with poor executive function would have greater per cent decrements in gait speed on complex as compared with usual (reference) walking tasks.

Methods

Study population

This research used baseline cross-sectional data from the InChianti study, a population-based epidemiological study of older people designed and conducted by the Laboratory of Clinical Epidemiology of the Italian National Research Council of Aging (INRCA) in collaboration with the Laboratory of Epidemiology, Demography, and Biometry at the National Institute on Aging (NIA). The survey was conducted in two Italian towns: Greve in Chianti and Bagno a Ripoli, both located in the Chianti geographic area (Tuscany). The baseline data were collected between September 1998 and March 2000. The InChianti study design, sampling and data collection procedures have been extensively reported elsewhere [13]. The study population for these analyses consisted of 737 men and women aged 65–102 who were randomly selected using a multistage stratified sampling method with the exclusion of those with cognitive impairment. The INRCA Institutional Review Board approved the InChianti Survey protocol. A description of the study was provided, and informed consent was obtained. Proxy consents were obtained for participants with significant cognitive or sensory problems.

Sociodemographic characteristics

Sociodemographic variables included in this study were age, gender and years of completed education.

Measures of cognitive status

Global cognitive status was assessed with the MMSE [14]. A cut off score of ≥24 was used as an inclusion criterion in this study [15, 16]. Previous studies have shown high rates of executive function impairment among community-dwelling older adults with normal MMSE scores [6, 17]. The decision to include in these analyses individuals with MMSE scores of ≥24 allows us to assess the relationship between executive function and performance of complex walking tasks/ gait speed without a possible confounding effect of severe cognitive impairment. Executive function was assessed using the TMT, a well-established psychomotor test originally developed as part of the Army Individual Test Battery [18]. The TMT has been widely used in clinical evaluations for the assessment of deficits in executive cognitive functions [5, 9, 19] and is administered in two parts. TMT Part A is a visual-scanning task; the participant is required to draw lines sequentially connecting consecutively numbered circles (1–25) randomly arranged on a page as quickly as possible. Part B adds a measure of cognitive flexibility [20], by asking the participant to connect the same number of circles in an alternating sequence of numbers and letters (1, A, 2, B etc.). Both parts of the tests are timed. For this analysis, we used a difference score defined as ΔTMT calculated as the difference between times (Part B–Part A). The ΔTMT score is used to control for the effect of motor speed on TMT performance and is considered a more accurate measure of executive function than the performance on Part B alone [19, 21]. Participants in this analysis were grouped according to tertiles of ΔTMT performance with the lowest tertile (ΔTMT<70 s) representing good executive function, the middle tertile (ΔTMT = 70–156 s) representing intermediate executive function and the highest tertile (ΔTMT>156 s) representing poor executive function.

Measures of physical performance

Mobility was assessed using walk tests that evaluate an individual's ability to walk under different conditions and different distances. For each complex task, we calculated per cent difference in gait speed compared with a non-complex reference walk done at the same distance and pace. Reference walks included 7 m walk tests conducted at a usual and fast pace as well as a 60 m fast pace walk. The 60 m walk was derived from the 400 m walk test that measures walking endurance. Participants performed the following complex dual-walk tasks: (i) talking while walking at a usual pace over a 7 m course; (ii) pick up an object from the ground while walking at a usual pace over a 7 m course; (iii) walking while carrying a light large package over a 7 m course at a usual pace; (iv) walking over two obstacles located on a 7 m course at a fast pace; (v) walking while wearing a weighted vest along a 20 m course for three laps (60 m) at a usual pace. [For detailed descriptions of the basic and complex walk tasks, please see Appendix 1 in the supplementary data on the journal website (http://www.ageing.oxfordjournals.org/)].

Measures of physiological impairments

Previous studies have identified the relevance of specific physiological systems for the maintenance of walking ability among older persons [13]. For this study, the following physiological measures were selected: (i) nerve conduction velocity; (ii) lower extremity muscle power; (iii) lower extremity range of motion (hip flexor–extensor and ankle dorsiflexion–plantarflexion); (iv) peripheral arterial circulation [ankle-brachial index (ABI)]; (v) haemoglobin; (vi) distance (3 m) and near (35 cm) tests of visual acuity. A complete description of the tests and physiological measures used in the InChianti study for the assessment of the degree of impairments in each of the main physiological subsystems has been reported elsewhere [13, 22].

Statistical analysis

General linear models (GLMs) were used to obtain adjusted gait speed means for each of the walk tasks and to determine whether gait speed varied significantly across tertiles of executive function. All analyses were adjusted for age, gender, years of completed education and selected physiological measures including nerve conduction velocity, lower extremity muscle power, lower extremity range of motion, ABI, haemoglobin and visual acuity. Contrast coding was used to conduct pairwise group comparisons (e.g. gait speed in low- versus high-ΔTMT groups). GLM was also used to examine group differences in the per cent change in gait speed. Per cent change in gait speed was calculated as follows: [(reference baseline walk speed – complex walk speed)/(reference baseline walk speed)] × 100, for each of the selected complex walks.

Results

The total study sample had a mean age of 72.7 years (SD 5.9), was predominantly female (53.5%, n = 394) and reported an average of 6.1 years of completed education (SD 3.4) and MMSE mean scores of 27.2 (SD 1.8).

Adjusted gait speed for the selected reference and complex walking tasks, according to ΔTMT groups (executive function), is summarised in Table 1. Compared to participants with low ΔTMT (good executive function), those with high ΔTMT (poor executive function) had significantly slower gait speed on the 7 m walk at usual pace, picking up an object, walking over an obstacle, 60 m walk at fast pace and walking while wearing a weighted vest. Group differences in per cent decline in gait speed on the selected complex walking tasks compared with reference walking tasks are summarised in Table 2. Per cent decline in gait speed was significant for walking over obstacles and walking while carrying a large package. For the 7 m obstacle walk, participants with high-ΔTMT (poor executive function) exhibited a significantly higher per cent decrement in gait speed than did the low-ΔTMT (good executive function) group (30 versus 24%). Contrary to our hypothesis, significantly greater decline in gait speed for the 7 m walk while carrying a package was found among participants in the low-ΔTMT (good executive function) group compared with the high-ΔTMT group (poor executive function) (5 versus 0%). Although not statistically significant, this trend was also observed in the 7 m walk and talk tasks.

Table 1. Gait speed on complex walking tasks (m/s) by Delta Trail Making Test (ΔTMT) groups (n = 737)

Walking tasks	High ΔTMT (>156 s)	Intermediate ΔTMT (70–156 s)	Low ΔTMT (<70 s)	P
Usual pace				
7 m walk (reference)	1.15	1.23	1.24	0.0001
Talking while walking	0.91	0.96	0.97	0.1165
Pick-up object	0.91	0.97	1.00	0.0001
Carrying a large package	1.17	1.20	1.18	0.3561
Fast pace				
7 m fast walk (reference)	1.60	1.61	1.64	0.5254
Walking with obstacles	1.13	1.20	1.25	0.0003
60 m fast walk (reference)	1.24	1.29	1.31	0.0034
Walking with a weighted vest	1.20	1.24	1.26	0.0348

Adjusted for age, sex, years of education, nerve conduction velocity, leg power, range of motion (ROM) of hip flexor, ROM hip extensor, ROM ankle dorsiflexion, ROM ankle plantarflexion, ankle-brachial index (ABI), haemoglobin and near and far visual acuity.

ΔTMT, difference score obtained by subtracting time to perform the TMT Part A from the time to perform Part B.

Table 2. Per cent decline in gait speed on complex tasks compared to reference walking tasks by Delta Trail Making Test (ΔTMT) groups (n = 737)

Walking tasks	High ΔTMT (>156 s)	Intermediate ΔTMT (70–156 s)	Low ΔTMT (<70 s)	P
Usual pace 7 m				
Talking while walking	20	21	22	0.7641
Pick-up object	22	21	19	0.0928
Carrying a large package	0[a]	3	5	0.0031
Fast pace 7 m				
Walking with obstacles	30[b]	26	24	0.0004
Fast pace 60 m				
Walking with a weight vest	6	7	5	0.3199

Adjusted for age, sex, years of education, nerve conduction velocity, leg power, range of motion (ROM) measures of hip and ankle, ankle-brachial index (ABI), haemoglobin and near and far visual acuity.

ΔTMT, difference score obtained by subtracting time to perform the TMT Part A from the time to perform Part B.

Per cent decline was calculated only for individuals with information on the reference baseline walk task and the complex walk task.

[a]Low versus high group, P = 0.0007.

[b]Low versus high group, P = 0.0004.

Discussion

This study examined the impact of cognition on physical function, specifically on walking ability among non-demented community-dwelling older adults, by evaluating whether executive function affects walking ability, with a higher impact on tasks that present particular challenges. The results of this study showed that the association between executive function and gait speed is task dependent and varies according to the degree of locomotor and sensorial adaptation required for the performance of complex walking tasks.

Executive function ability plays an important role in older adults' ability both to effectively adapt to complex environments and to adequately allocate the attentional resources that are necessary to successfully complete a given task [3, 5, 7]. Previous research using dual-task paradigms has shown an association between cognition and sensorimotor adaptation. Walking and balance control are increasingly dependent on cognitive control as a compensatory mechanism for sensory impairments, decreased attentional resources and other age-related deficits [23–27].

Executive function had an effect on gait speed for some (pick up an object, walking over obstacles, carrying a weighted vest) but not for others (talking while walking, carrying a large package) of the selected complex walking tasks included in this study. Previous studies have shown that during level walking, carrying a light package that obscures vision has no effect on gait velocity and lower extremity kinematics; in this case, few gait adaptations may be required for the performance of this task [28]. Consequently, subsequent demands for appropriate executive control may also be low. In contrast, picking up an object or stepping over obstacles requires both the modification of gait kinematics and changes in the frequency and duration of visual sampling of the environment [29]. Demands on executive control would be correspondingly high in response to the increased demands for sensorimotor adaptation inherent in these tasks.

In this study, participants with poor executive function exhibited significantly slower gait speed compared with those with good executive function, for both walking and picking up an object and walking over obstacles tasks. These findings are consistent with previous studies that have reported the existence of an association between executive control and walking speed, as well as increased difficulty in performing complex instrumental activities of daily living among subjects with executive dysfunction [3, 5, 9, 23, 30].

Executive function differences in per cent change were also dependent on the nature of the dual tasks. In the walking while carrying a package task, the greatest per cent decrement in gait speed was found among the good executive function performance group. In contrast, in the walk over obstacles task, poor executive function performers showed significantly higher per cent decline in gait speed compared with good performers. In the walk and talk tasks, there were no significant executive function group differences. These results are consistent with recent experimental work that has reported an association between the nature/characteristics of dual tasks and cost on gait speed [30]. Baddeley and Hitch's [31] model of a central executive that controls cognitive and attentional resources offers a way of understanding these findings. In dual-task paradigms, the cost of performance on the primary task is greater when the two tasks are in the same perceptual domain. The complex walking tasks selected for this analysis represent dual tasks within similar (e.g. walking with obstacles) and different (e.g. walking while talking) perceptual domains.

Poor executive function may also be associated with decreased awareness of a risk inherent in a task, and subsequently the need to modify behaviour in response to that risk. Indeed, declines in gait speed can be an appropriate adaptive behaviour under certain conditions such as walking on icy surfaces, walking under low-light conditions or walking on uneven surfaces while carrying a load [11, 29]. In these particular situations, failure to adapt gait speed to a change in environmental conditions may represent a judgment error consistent with lower executive function control. The fact that good executive function performers exhibited per cent declines in gait speed for the walk while carrying the package task which were significantly greater than those of poor performers (5 versus 0%; $P<0.0031$) suggests that elements such as perceived task-associated risk, task-accuracy estimation and self-monitoring all of which are considered to be under executive function control [1, 8, 9] may play a relevant role in the performance of this task and could possibly explain the group differences observed in this study.

Results from our study support the concept that examining gait speed on complex walking tasks in relationship to a reference baseline task can be used to infer an individual's ability to adapt gait to changing task demands. However, our findings suggest that a reduction in gait speed is not always indicative of impaired locomotor adaptation. We suggest that a reduced ability to adapt gait speed to task demands can manifest either as an inappropriate (or disproportionate) reduction in gait speed or alternatively as a failure to modify gait speed appropriately to increased task demands. Finally, our results suggest that the clinical interpretation of complex tests of physical function, particularly among older people, must include a careful consideration of both the nature of the selected complex task and the intra-individual characteristics of the target population.

One limitation of this study is that we used cross-sectional data that do not allow us to assess causal relationships. Longitudinal research aimed at assessing the predictive value of executive function on walking ability is needed to better understand the mechanisms whereby the central nervous system affects physical function in later years and to identify possible target areas for preventive interventions. Another important limitation is that executive function in the InChianti study was assessed solely with the TMT. Although this is a widely used test, there are other measures of executive control that in conjunction with the TMT would have provided a more comprehensive evaluation of executive control functions.

Complex walking tasks measure the ability to walk in diverse and challenging environments and may provide a better indication of the ability to function in daily life than simple standardised gait speed measurement. Findings of this study suggest that executive function significantly affects older adults' ability to appropriately adapt to environmental challenges and that this effect varies by the complexity of the task. These results further highlight the importance of cognitive flexibility and psychomotor speed for the performance of certain complex tasks. Further research is needed to determine whether improvement in executive function abilities translates to better physical function and performance on selected complex walking tasks.

Key points

- What is already known on this topic: there is an association between cognitive status and physical function. Older adults who perform poorly in cognitive tests show significant declines in physical performance and greater dependency in basic and instrumental activities of daily living.
- What this study adds: executive function affects older adults' performance of dual-task physical tests. The cost of adding a challenge to a basic physical task differs by executive function level and the characteristics of the task. The clinical interpretation of complex tests of physical function among older adults must carefully consider the nature of the selected performance test and the individual characteristics of the target population.

Conflicts of interest

The authors declare that they have no conflicts of interest related to this work.

Sources of funding

The InChianti study was supported as a 'targeted project' (ICS 110.1\RS97.71) by the Italian Ministry of Health and in part by the Intramural Research Program of the NIH (Contracts N01-AG-916413 and N01-AG-821336 and Contracts 263 MD 9164 13 and 263 MD 821336). The financial sponsors play no role in the design, execution, analysis, data interpretation or writing of this article.

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Received 9 March 2006; accepted in revised form 16 August 2006