Executive Function Correlates with Walking Speed in Older Persons: The InCHIANTI Study

Alesandro Ble, MD, Stefano Volpato, MD, MPH,† Giovanni Zuliani, MD, PhD,† Jack M. Guralnik, MD, PhD,‡ Stefania Bandinelli, MD,§ Fulvio Lauretani, MD,§ Benedetta Bartali, RD,‖ Cinzia Maraldi, MD,† Renato Fellin, MD,† and Luigi Ferrucci, MD, PhD**

OBJECTIVES: To study the association between performance on psychological tests of executive function and performance on lower extremity tasks with different attentional demands in a large sample of nondemented, older adults.

DESIGN: Cross-sectional study.

SETTING: Community-based.

PARTICIPANTS: Nine hundred twenty-six persons aged 65 and older, without dementia, stroke, parkinsonism, visual impairment, or current treatment with neuroleptics, enrolled in a large epidemiological study.

MEASUREMENTS: Trail Making Test (TMT) parts A and B and two performance-based measures of lower extremity function that require different executive/attentional-demanding skills: walking speed on a 4-m course at usual pace and walking speed on a 7-m obstacle course at fast pace. A difference score (Delta TMT), obtained by subtracting time to perform part A from time to perform part B of the TMT, was used as an indicator of executive function. Based on Delta TMT, subjects were divided into poor performance, intermediate performance, and good performance.

RESULTS: After adjustment, no association between Delta TMT and 4-m course usual-pace walking speed was found. Participants with poor Delta TMT and with intermediate Delta TMT performance were more likely to be in the lowest tertile for 7-m obstacle course walking speed.

CONCLUSION: In nondemented older persons, executive function is independently associated with tasks of lower extremity function that require high attentional demand.
J Am Geriatr Soc 53:410–415, 2005.

Key words: aging; cognitive function; executive function; lower extremity function; walking speed; InCHIANTI

From the *Longitudinal Studies Section, Clinical Research Branch, National Institute on Aging, National Institutes of Health, Baltimore, Maryland; †Department of Clinical and Experimental Medicine, Section of Internal Medicine and Geriatrics, University of Ferrara, Ferrara, Italy; ‡Laboratory of Epidemiology, Demography and Biometry, National Institute on Aging, National Institutes of Health, Bethesda, Maryland; §Laboratory of Clinical Epidemiology, Italian National Institute of Research and Care on Aging, Florence, Italy; and ‖Division of Nutritional Sciences, Cornell University, Ithaca, New York.

Address correspondence to Luigi Ferrucci, MD, PhD, National Institutes of Heath, National Institute on Aging, Harbor Hospital, 3001 S. Hanover Street, Baltimore, MD 21225. E-mail: ferruccilu@grc.nia.nih.gov

It has been suggested that decline in cognitive function with the aging process is one of the determinants of walking difficulty that is often observed in older persons.[1] Reduced performance on gait tests and specific gait abnormalities have been described in persons with dementia,[2,3] but data on the relationship between cognitive function and lower extremity performance in nondemented older persons are limited and somewhat controversial.[1,4,5]

It was hypothesized that cognitive decline affects gait, especially when impaired executive function accompanies it. Executive function is defined as the cognitive ability to independently perform complex, goal-directed, and self-serving behaviors.[6] Age-related decline in executive function has been well documented.[7,8]

In this study, the relationship between executive function and walking speed was investigated in a sample of nondemented older persons. It was hypothesized that the effect of executive function on gait would be more evident in performance-based tests that are more challenging than in traditional tests of timed walking.

METHODS

Study Sample

The InCHIANTI study is a population-based epidemiological study performed in Greve in Chianti and Bagno a Ripoli, two small towns in the Tuscany region of Italy. The study design, which the Italian National Institute of Research and Care on Aging Review Board approved, has been reported elsewhere.[9] Briefly, in 1998, 1,260 subjects aged 65 and older were randomly selected from the population registry of the two municipalities. Of these, 1,154 (89%) agreed to be enrolled in the project and signed an informed participation consent. Study participants responded to a structured home interview and underwent a full medical, neurological, and functional examination

0002-8614/05/$15.00

performed by a trained physician, a neurologist, and a physical therapist.

Eighty-two subjects affected by dementia, 57 affected by stroke, and 19 affected by parkinsonism were excluded from the analysis based on standardized criteria. In particular, stroke was ascertained as self-reported or documented previous physician's diagnosis or positive medical history of at least one episode of rapidly developing clinical sign of neurological damage lasting 24 hours or longer, with no apparent cause other than vascular origin;[10] parkinsonism was ascertained as self-reported or documented previous physician's diagnosis or typical features including at least slowness of voluntary movement plus one of the following signs: "resting" tremor, stooped posture, axial instability, rigidity, and festinating gait.[11,12] Subjects who scored less than 26 on the Mini-Mental State Examination (MMSE)[13] underwent an extensive neuropsychological examination by a neurologist with expertise in cognitive impairment. The *Diagnostic and Statistical Manual of Mental Disorders, Third Edition, Revised,* criteria were used to establish the diagnosis of dementia. In addition, 41 subjects with a MMSE score below 18 who did not meet the criteria for dementia, 22 participants treated with neuroleptics, and seven subjects with visual impairment (Snellen's eye chart score $<20/200 = 0.1$) according to the National Academy of Science criteria,[14] were also excluded from the analysis. No patients presented with a history of demyelination diseases.

Cognitive Measures

Trained interviewers administered the MMSE and the Trail Making Test (TMT). The TMT is a paper-and-pencil task given in two parts: A (TMT-A) and B (TMT-B). On TMT-A, participants were required to connect randomly arranged circles, numbered from 1 to 25, spread over a sheet of paper, into an ascending numeric sequence as quickly as possible (1-2-3-4, etc.). On TMT-B, participants were required to alternatively connect circles containing numbers (from 1 to 12! ~~13)~~ and circles containing letters (from A to L), in numeric and alphabetical order (1-A, 2-B, 3-C, etc.). A maximum allowed time of 600 seconds was allowed for each part of the test. It was decided to extend the usual cutoff time of 300 seconds[15] because, in the authors' experience, a meaningful number of older persons require more than 300 seconds to complete the test (TMT-A: 0.6% of the study sample; TMT-B: 6.6%). According to one version,[15] the examiner pointed out errors as they occurred so that the subject could always complete the test without errors and the scoring could be based on time alone. Age, educational level (persons unaccustomed to handling pencils), visual function, visual-motor coordination, difficulty comprehending instructions, motor speed,[16] and dementia influence performance in the TMT.

To remove the upper extremity motor speed element from the test evaluation, a difference score (Delta TMT—time on part B minus time on part A) was calculated, according to the literature.[15,17] It has been suggested that Delta TMT is a more accurate measure of executive skills than performance on TMT-B.[18] TMT-A and TMT-B are almost equivalent in their demands for simple sequencing, visual scanning, and psychomotor functioning. Part B requires greater cognitive flexibility than part A, which can be selectively estimated as Delta TMT.[18] Study participants were grouped according to Delta TMT performance; subjects with Delta TMT greater than 187 seconds were considered pathological (poor performance);[19] the median value among the remaining participants was used to define good performance (Delta TMT <78 seconds) and intermediate performance (Delta TMT between 78 and 187 seconds).

Physical Performance Measures

Mobility was assessed using two performance-based measures that require different executive/attentional-demanding abilities: walking speed on a 4-m course at usual pace and walking speed on a 7-m obstacle course at fast pace.

To measure usual walking speed in the 4-m task, two photocells connected with a recording chronometer were placed at the beginning and at the end of a 4-m course. Participants were instructed to stand with both feet touching the starting line and to begin walking at their usual pace after a verbal command. The time between the activation of the first and the second photocells was recorded, and the average time of two walks was used in the analysis. Tertiles of 4-m walking speed were defined as speed greater than 1.14 m/s (highest tertile), between 0.95 m/s and 1.14 m/s (middle tertile) and 0.95 m/s or less (lowest tertile). Conceptually, this performance-based test poses few attentional/executive demands because simple gait is performed as an almost automatic task.[20]

To measure walking speed on a 7-m obstacle course at fast pace, two photocells connected with a recording chronometer were placed at the beginning and end of a 7-m course interrupted by two obstacles: a foam rubber obstacle, 6 cm tall, was placed 1 m from the starting line, and a second one, 30 cm tall, was placed 5 m from the starting line. The research assistant demonstrated the correct performance of the task to the subject. Subjects were instructed to stand with both feet touching the starting line and to begin walking as fast as possible, without running, after a verbal command. The time between the activation of the first and the second photocell was recorded. For this task, only one attempt was allowed. Tertiles of 7-m speed, fast pace with obstacles were defined as speed greater than 1.30 m/s (highest tertile), between 1.04 m/s and 1.30 m/s (middle tertile), and 1.03 m/s or less (lowest tertile). The 7-m, fast-pace obstacle course has high demands with respect to attention, motor control, and motor planning.[20,21] A previous study showed that poor performance in an obstacle course was a predictor of falls.[22]

Demographic Characteristics and Health Status

Education was assessed at the maximum achieved educational level (years of schooling). Body mass index (BMI) (kg/m^2) was computed using measured height and weight and categorized as low BMI ($<18.7\,kg/m^2$), normal BMI ($18.7–24.9\,kg/m^2$), and high BMI ($>24.9\,kg/m^2$). Grip strength was assessed using a handgrip dynamometer and was used as a general indicator of muscular strength because it is a reliable measure of upper extremity strength, which is highly correlated with lower extremity strength in older persons.[23]

The Italian version of the Center for Epidemiologic Studies Depression Scale (CES-D)[24] was used to evaluate depressive symptoms. The CES-D has a potential range of 0 to 60, with higher scores indicating more depressive symptoms. Individuals with a score of 16 or greater were classified as having high depressive symptoms.

The Snellen letter chart was used to assess visual acuity, with corrective lenses permitted using standardized methods. The Snellen score was used in the analysis as a continuous variable. To assess auditory function, subjects were required to answer to the question: “Do you have any hearing problem?” Subjects who answered yes were classified as having auditory problems regardless of the severity of the impairment.

The presence of the following medical conditions was established using standardized criteria that combined information from self-reported history, medical records, and a clinical medical examination: liver disease, gastrointestinal disease, angina pectoris, acute myocardial infarction, congestive heart failure, pulmonary disease, fracture, knee osteoarthritis, diabetes mellitus, hypertension, peripheral arterial disease, osteoporosis, renal failure, and cancer. Number of diseases (0–14) was used to assess the burden of comorbidity. A dichotomous variable indicating the presence of knee osteoarthritis was introduced in the final multivariate model to account for the influence of this highly prevalent condition on lower extremity function.

Pathological neurological signs detected in older persons without stroke, Parkinson’s disease, or dementia might be an epiphenomenon of subclinical or undiagnosed brain damage (or aging-related declines) that could adversely affect physical performance. To account for the potential confounding effect of such conditions, the following neurological signs were included in the analysis as covariates: neck rigidity, lower extremity rigidity, hand palm stereognosis, and Babinski sign.

Health Behaviors

Subjects were classified as current, past, or never smokers, based on self-report. A dummy variable was used to indicate two categories: past or current smokers versus never smokers.

Alcohol consumption was measured as average daily intake of alcohol during the previous year using data collected in the context of a comprehensive food frequency questionnaire.[25]

Statistical Analysis

Walking speed for each of two performance tasks is reported as mean ± standard error for each tertile of Delta TMT. Differences between groups were tested in age-and sex-adjusted analyses of covariance and tests for trend.

Polycotomous logistic regression models were used to assess the association between walking speed and Delta TMT groups. Odds ratios adjusted for confounders were calculated, comparing participants with poor and intermediate performance on Delta TMT with those with good performance on Delta TMT, considered as the reference group.

RESULTS

The study sample included 926 persons, 408 men and 518 women, aged 65.1 to 95.3 (mean = 74.6) with an average educational level of 5.6 school years (Table 1).

Age- and sex-adjusted walking speed, according to executive function groups, is reported in Figure 1. Walking speed for the 4-m course at usual pace and walking speed

Table 1. Descriptive Statistics for the Study Participants

Characteristic	Value	
Age, mean ± SD (range)	74.6 ± 6.7	(65.1–95.3)
Male,%	44.0	
Years of school, mean ± SD (range)	5.6 ± 3.3	(0–22)
Mini-Mental State Examination score, mean ± SD (range) (possible range 0–30)	25.5 ± 2.8	(18–30)
TMT A time, sec, mean ± SD (range)	94.3 ± 64.4	(21–600)
TMT B time, sec, mean ± SD (range)	185.4 ± 105.5	(52–600)
Delta TMT time, sec, mean ± SD (range)*	107.2 ± 81.3	(7–557)
4-m walking speed, usual pace, m/sec, mean ± SD (range)	1.03 ± 0.24	(0.18–2.00)
7-m walking speed, fast pace with obstacles, m/sec, mean ± SD (range)	1.16 ± 0.34	(0.14–2.31)
Body mass index, kg/m^2, mean ± SD (range)	27.5 ± 4.0	(17.9–46.5)
Grip strength, kg, mean ± SD (range)	27.2 ± 11.4	(4–58)
Center for Epidemiologic Study Depression Scale score, mean ± SD (range) (possible range 0–60)	12.6 ± 8.6	(0–48)
Visual acuity, mean ± SD (range) (Snellen score: possible range 0.1–2.0)	0.41 ± 0.10	(0.1–0.5)
Auditory impairment†, %	26.3	
Number of diseases, mean ± SD (range)‡	2.3 ± 1.2	(0–7)
Knee osteoarthritis, %	23.1	
Never smoked, %	89.6	
Alcohol consumption, g/d, mean ± SD (range)	14.5 ± 19.4	(0–151)

* Time on B minus time on A.
† Any degree of auditory impairment (from self-report).
‡ Diseases considered: liver diseases, gastric diseases, angina, acute myocardial infarction, congestive heart failure, pulmonary disease, fractures, knee osteoarthritis, diabetes mellitus, hypertension, peripheral arterial disease, osteoporosis, renal failure, cancer.
TMT = Trail Making Test; SD = standard deviation.

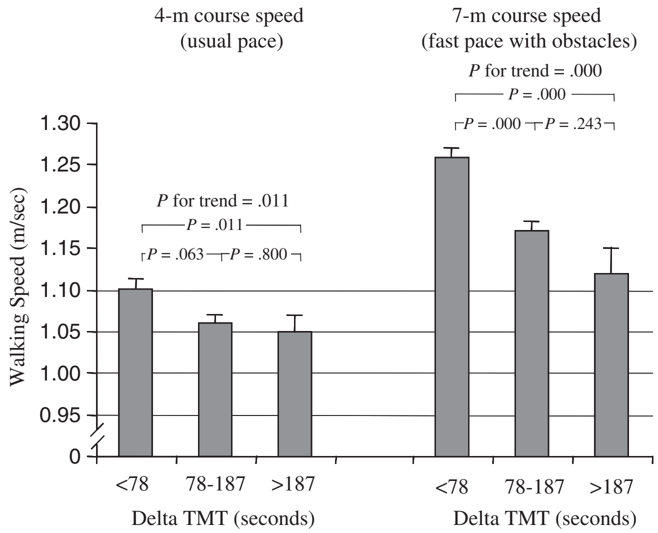

Figure 1. Age- and sex-adjusted walking speed in usual-pace 4-m course and fast-pace 7-m course with obstacles, according to time on Part B minus time on Part A (Delta TMT).

for the 7-m obstacle course were progressively slower from good to poor Delta TMT performance.

After adjustment for age and sex, participants with poor Delta TMT performance were more likely than subjects with good Delta TMT performance to be in the lowest than in the highest 4-m walking speed tertile (Model 1A, Table 2) ($P = .05$). However, after adjusting for potential confounders, the association between Delta TMT performance and 4-m usual pace walking speed was substantially attenuated and no longer statistically significant (Model 2A, Table 2) ($P = .40$).

When the same analysis shown in Table 2 was repeated using walking speed on the 7-m obstacle course as the dependent variable, the results were substantially different. After adjusting for age and sex, subjects with poor ($P = .007$) and intermediate Delta TMT performance ($P = .005$) were more likely than those with good performance to be in the lowest than in the highest 7-m obstacle course walking speed tertile (Table 2, Model 1B). More important, contrary to what was observed for the 4-m usual-pace test, these findings were virtually unchanged after adjusting for multiple confounders (poor vs good Delta TMT performance: $P = .01$; intermediate vs good Delta TMT performance: $P = .02$) (Table 2, Model 2B).

In the subsample of participants without cognitive impairment (MMSE ≥ 24), after adjustment for multiple potential confounders, subjects with intermediate Delta TMT performance were 2.3 times as likely to be in the lowest 7-m obstacle course speed tertile (95% confidence interval (CI) = 1.13–4.90, $P = .02$) as subjects with good performance. Participants with poor Delta TMT performance were 4.2 times as likely to be in the lowest 7-m obstacle course walking speed tertile as executive-healthy high-functioning subjects (95% CI = 1.25–13.60, $P = .02$).

DISCUSSION

In this study, no independent association was found between Delta TMT and walking speed on a 4-m course at

Table 2. Polycotomous Logistic Regression Model Relating Walking Speed at Usual Pace on 4-M Course and Walking Speed at Fast Pace on 7-M Course Fast Pace with Two Obstacles to Delta TMT*

	Lowest Versus Highest Tertile		Middle Versus Highest Tertile	
Delta TMT performance (sec)	Odds Ratio (95% Confidence Interval) *P*-value			
4-m course walking speed, normal pace				
Model 1A†				
Good§	1 —	—	— —	—
Intermediate‖	1.53 (0.94–2.50)	.09	1.33 (0.88–2.00)	.16
Poor¶	2.07 (1.01–4.33)	.049	1.26 (0.63–2.51)	.50
Model 2A‡				
Good§	1 —	—	1 —	—
Intermediate‖	1.67 (0.86–3.22)	.13	1.32 (0.80–2.17)	.27
Poor¶	1.57 (0.54–5.52)	.40	1.31 (0.57–2.99)	.52
7-m course walking speed, fast pace with two obstacles				
Model 1B†				
Good§	1 —	—	— —	—
Intermediate‖	2.16 (1.26–3.70)	.005	1.47 (0.96–2.26)	.08
Poor¶	3.22 (1.37–7.56)	.007	1.91 (0.90–4.04)	.09
Model 2B‡				
Good§	1 —	—	1 —	—
Intermediate‖	2.37 (1.17–4.82)	.02	1.02 (0.60–1.72)	.93
Poor¶	4.39 (1.40–13.73)	.01	1.54 (0.63–3.75)	.34

* Time on Trail Making Test (TMT) part B minus time on part A.
† Adjusted for age and sex.
‡ Adjusted for age, sex, educational level, Mini-Mental State Examination score, body mass index, muscular strength, depression, visual acuity, hearing impairment, smoking history, alcohol intake, number of diseases, osteoarthritis of the knee, and neurological signs.
§ <78; ‖ 78–187; ¶ >187.

usual pace, a task that uses highly learned motor skills. Conversely, a strong, independent association between Delta TMT and walking speed was observed on a 7-m obstacle course at fast pace, a task that is considerably more attention demanding. This relationship was confirmed in a subsample of participants free of cognitive impairment. These findings suggest that executive function may play a significant role in the ability of older adults to manage complex lower extremity motor tasks and is much less important for highly learned tasks such as usual-pace gait.

These results are in agreement with the findings of another study that showed that, in a sample of subjects affected by Alzheimer's disease,[2] impaired executive function was associated with greater gait variability in a dual task that required divided attention between a cognitive and a motor task, but not in simpler tests such as usual gait. As far as the authors know, no previous studies have tested this same hypothesis in a population-based sample of nondemented older persons. Two previous studies found an association between executive function and overall measures of motor function, including lower extremity tasks,[1,4] but they did not provide any information about the differential contribution of executive function on tasks of different complexity and attentional requirements. A recent 7-year longitudinal study in healthy older adults[5] showed that changes in overall cognition were similarly associated with decrement in attentional-demanding motor as well as routine motor tasks. In contrast with the current findings, the authors suggested that successful and rapid execution of motor tasks demands cognitive processing regardless of the complexity of the task. However, because they did not include a specific measure of executive function, their findings are not directly comparable with those of the current study.

A possible explanation of these findings is that executive function might be a critical component of the ability to perform lower extremity complex tasks, and therefore it may be an integral part of the goal-directed walking control system. According to a widely accepted paradigm of walking,[26] performing a challenging or complex locomotor task requires integrity and functionality of the neurological structures that are in charge of executive function. Thus, performance tests that are particularly challenging and attention demanding may reveal even minor dysfunctions in these areas. An interesting alternative explanation of the current findings underlines the important role played by basal ganglia on motor control, which may affect performance in TMT. In a sample of patients affected by Parkinson's disease, therapeutic stimulation of the subthalamic nucleus increased the performance in Delta TMT.[27] Moreover, in a sample of patients with Huntington's disease, one study[28] found a direct association between basal ganglia atrophy and poor performance on the TMT. Thus, it is possible that in the current study, the TMT score captured a subclinical dysfunction of the basal ganglia responsible for gait abnormality and executive impairment.

This study has several limitations. The cross-sectional nature of the data collected does not allow inference of causal associations. One longitudinal study[29] demonstrated that women who were more physically active were less likely to develop cognitive decline. So, contrary to the hypothesis of the current study, the possibility that better function and higher activity might actually improve executive function cannot be excluded. The assessment of cognitive function in this study was limited to the MMSE and TMT. Although there is evidence that the TMT captures important aspects of executive function, it is neither a perfectly selective nor completely exhaustive measure of this complex neuropsychological function. Unfortunately, no other cognitive evaluations for executive function were performed in the InCHIANTI study. A third important limitation of the study is the absence of neuroimaging that would help to evaluate the anatomical correlates of the association between executive and motor function. In particular, neuroimaging may help detect subclinical cerebrovascular lesions (such as white matter lesions) associated with executive dysfunction and gait disturbance. Finally, a high prevalence of subjects in this study population had a low educational level. Because educational status may affect cognitive and physical performance, these findings may not be generalizable to other populations with higher levels of formal education.

If executive function is important in the performance of complex mobility tasks, then the age-related decline in executive function described by many observational studies is not without consequences for the health of older individuals. Impaired executive function may result in reduced ability to quickly plan effective and efficient motor strategies that are required in the execution of complex attention-demanding physical tasks, such as climbing over an obstacle, avoiding domestic or street hazards, and avoiding injurious falls. It is notable that poor performance on TMT is one of the best predictors of nonsyncopal falls in older people.[30] Interventions that prevent decline of or improve executive function may also improve the performance of complex lower extremity motor tasks in older adults without dementia.

REFERENCES

1. Binder EF, Storandt M, Birge SJ. The relation between psychometric test performance and physical performance in older adults. J Gerontol A Biol Sci Med Sci 1999;54A:M428–M432.
2. Sheridan PL, Solomont J, Kowall N et al. Influence of executive function on locomotor function: Divided attention increases gait variability in Alzheimer's disease. J Am Geriatr Soc 2003;51:1633–1637.
3. Waite ML, Broe GA, Grayson DA et al. Motor function and disability in the dementias. Int J Geriatr Psychiatry 2000;15:897–903.
4. Carlson MC, Fried LP, Xue QL et al. Association between executive attention and physical functional performance in community-dwelling older women. J Gerontol B Psychol Sci Soc Sci 1999;54B:S262–S270.
5. Tabbarah M, Crimmins EM, Seeman TE. The relationship between cognitive and physical performance. MacArthur Studies of Successful Aging. J Gerontol A Biol Sci Med Sci 2002;57A:M228–M235.
6. Malloy PF, Richardson ED. Assessment of frontal lobe functions. J Neuropsychiatry 1994;6:399–410.
7. Brennan M, Welsh MC, Fisher CB. Aging and executive functions skill: An examination of a community-dwelling older adult population. Percept Mot Skills 1997;84:1187–1197.
8. Fisk JE, Warr P. Age and working memory: The role of perceptual speed, the central executive, and the phonological loop. Psychol Aging 1996;1:316–323.
9. Ferrucci L, Bandinelli F, Benvenuti E et al. Subsystems contributing to the decline in ability to walk: Bridging the gap between epidemiology and geriatric practice in the InCHIANTI Study. J Am Geriatr Soc 2000;48:1618–1625.
10. The World Health Organization MONICA Project (monitoring trends and determinants in cardiovascular disease): A major international collaboration. WHO MONICA Project Principal Investigators. J Clin Epidemiol 1988; 41:105–114.
11. Gibb WR, Lees AJ. A comparison of clinical and pathological features of young and old onset Parkinson's disease. Neurology 1988;38:1402–1406.

12. Gibb WR. Neuropathology in movement disorders. J Neurol Neurosurg Psychiatry 1989; Suppl: 55–67.
13. Folstein MF, Folstein S, McHugh PR. 'Mini-mental state'. A practical method to grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198.
14. Visual Impairments: Determining Eligibility for Social Security Benefits [online]. Board on Behavioral, Cognitive, and Sensory Sciences and Education. Available at www.nap.edu/openbook/0309083486/html/56.html Accessed December 3, 2004.
15. Lezak MD. Orientation and attention. In: Lezak MD. Neuropsychological Assessment, 3rd Ed. New York: Oxford University Press, 1995, pp 335–384.
16. Savage RD, Britton PG, Bolton N. Intellectual Functioning in the Aged. New York: Harper & Row, 1973.
17. Corrigan JD, Hinkeldey NS. Relationship between Parts A and B of Trail Making Test. J Clin Psychol 1987;43:402–408.
18. Drane DL, Yuspel RL, Huthwaite MA. Demographic characteristics and normative observations for derived Trail Making Test Indices. Neuropsychiatry Neuropsychol Behav Neurol 2002;15:39–43.
19. Giovagnoli AR, Del Pesce M, Mascheroni S et al. Trail making test: Normative values from 287 normal adult controls. Ital J Neurol Sci 1996;17:305–309.
20. Abernethy B, Hanna A, Plooy A. The attentional demands of preferred and non-preferred gait patterns. Gait Posture 2002;15:256–265.
21. Lajoie Y, Teasdale N, Bard C et al. Attentional demand for static and dynamic equilibrium. Exp Brain Res 1993;97:139–144.
22. Means KM, Rodell DE, O'Sullivan PS. Obstacle course performance and risk of falling in community-dwelling elderly persons. Arch Phys Med Rehabil 1998;79:1570–1576.
23. Visser M, Deeg DJ, Lips P et al. Skeletal muscle mass and muscle strength in relation to lower extremity performance in older men and women. J Am Geriatr Soc 2000;48:381–386.
24. Fava GA. Assessing depressive symptoms across cultures. Italian validation of the CES-D self-rating scale. J Clin Psychol 1983;39:249–251.
25. Pisani P, Faggiano F, Krogh V et al. Relative validity and reproducibility of a food frequency dietary questionnaire for use in the Italian EPIC centers. Int J Epidemiol 1997;26:S152–S160.
26. Grillner S, Parker D, el Manira A. Vertebrate locomotion—a lamprey perspective. Ann N Y Acad Sci 1998;860:1–18.
27. Jahanshahi M, Ardouin CM, Brown RG et al. The impact of deep brain stimulation on executive function in Parkinson's disease. Brain 2000;123: 1142–1154.
28. Starkstein SE, Brandt J, Folstein S et al. Neuropsychological and neuroradiological correlates in Huntington's disease. J Neurol Neurosurg Psychiatry 1988;51:1259–1263.
29. Yaffe K, Barnes D, Nevitt M. A prospective study of physical activity and cognitive decline in elderly women. Arch Intern Med 2001;161: 1703–1708.
30. Nevitt MC, Cummings SR, Kidd S et al. Risk factors for recurrent nonsyncopal falls. A prospective study. JAMA 1989;12:2663–2668.