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Association Between Executive Attention and Physical Functional Performance in Community-Dwelling Older Women

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Objectives. Executive functions supervise the contents of working memory, where information from long-term memory is integrated with information in the immediate present. This study examined whether executive attentional abilities were uniquely associated with the performance of complex, instrumental activities of daily living (IADLs) in cognitively intact and physically high-functioning older women.

Methods. Participants were 406 community-residing, older women aged 70–80 years in the Women's Health and Aging Study (WHAS) II, screened to be physically high functioning and cognitively intact using the Mini-Mental State Exam. Hierarchical regression models, adjusted for demographic and disease variables, were used to evaluate the association of cognitive domains, including executive attention, memory, psychomotor speed, and spatial ability with summary measures of IADL (e.g., looking up and dialing a telephone number) and mobility-based ADL (e.g., walking 4 meters) function.

Results. Tests of executive attention were associated with performance on IADLs (6.6%) and, to a lesser degree, mobility-based ADLs (1%), adjusting for demographic and disease variables. In particular, the mental flexibility component of the Trail Making Test accounted for the majority of attentional variance in IADL performance. Older age, lower education, and African American race were also associated with poorer physical test performances.

Discussion. Executive difficulties in flexibly planning and initiating a course of action were selectively associated with slower performance of higher-order IADL tests, relative to other domains of cognition, in a high-functioning, community-based older cohort. These results suggest that executive functions may be important in mediating the onset and progression of physical functional declines.

NEUROPSYCHOLOGICAL data in healthy older adults indicate that the frontal lobes undergo the most significant age-related changes relative to other cortical structures (Shaw et al., 1984; Terry, DeTeresa, & Hansen, 1987). These changes are typically subtle, variable across individuals, and evident after 65 years of age. Recent theories of aging propose that most age-related cognitive declines in memory and attention stem from degradations in executive function, putatively associated with the frontal lobes (Dempster, 1992; Lezak, 1995; Shimamura, 1995; Stuss & Benson, 1984). Executive functions supervise the contents of working memory, a metaphorical "space" where information from long-term memory is integrated with information in the immediate present to plan, initiate, and carry out a course of action (Cummings, 1990; Fuster, 1989; Krasnegor, Lyon, & Goldman-Rakic, 1997). How do these age-related changes in executive function impact on the performance of every day activities?

In psychogeriatric patients, cognitive impairment on general mental status exams, such as the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975) or the Dementia Rating Scale (Mattis, 1988), is associated with impairment on complex, instrumental activities of daily living (IADLs; Lemsky, Smith, Malec, & Ivnik, 1996; McCue, Rogers, & Goldstein, 1990; Nadler, Richardson, Malloy, Marran, & Hostetler-Brinson, 1995; Richardson, Nadler, & Malloy, 1995; Potter, Evans, & Duncan, 1995; Skurla, Rogers, & Sunderland, 1988). Self-reported difficulties in performing many routine daily activities are among the criteria used for the clinical diagnosis of dementia. Difficulties in performing everyday activities may remain undetected, as patients in the early stages of dementia often underreport functional difficulties that are observed on performance. The degree of their inaccuracy is correlated with the degree of their cognitive impairment (DeBettignies, Mahurin, & Pirozzola, 1990; Guralnik, Branch, Cummings, & Curb, 1989; Sager et al., 1992). Because patients show generalized cognitive impairment, it is not yet clear whether early functional declines in dementia patients are mediated by executive deficits or by memory deficits seen early in the course of progressive dementias, such as Alzheimer's disease (Welsh, Butters, Hughes, Mohs, & Heyman, 1991). Overall, general evaluations in patients do not provide insight into how age-related changes in executive function may impact on the performance of complex activities of daily living (ADLs), such as preparing a meal or using the telephone.

The physical function literature has also demonstrated that, when self-report measures are used, many older adults reporting no difficulty in tasks of daily life nevertheless experience mild functional loss upon testing (Fried et al., 1996). This mild functional loss, hypothesized to represent a preclinical stage of disability, appears to predict subsequent disability. Preclinical difficulties in performance-based measures of mobility predicted incident mobility disability (Fried, Bandeen-Roche, Chaves, & Johnson, in press) and declines in mobility-based ADLs four years later (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). Seeman and colleagues (1994) have further demonstrated the predictiveness of baseline cognitive function on performance-based improvements in physical function 3 years later using a summary score comprising language, verbal and nonverbal memory, and visuospatial domains. However, it did not predict significant decline, perhaps because the summary cognitive score incorporated no measure of executive function.

Motor-based, executive functions have been associated with both basic ADL and complex IADL test performances in geriatric patients (Nadler et al., 1995) and community-dwelling, older adults, many of whom reported difficulty on one or more ADLs (Grigsby, Kaye, Baxter, Shetterly, & Hamman, 1998). These studies highlight the potential role that executive functions play on everyday functioning. However, it remains to be shown (a) whether this association can be observed in cognitively intact, physically high-functioning older adults, and (b) whether the performance of complex activities is selectively associated with executive abilities, or also with other domains of cognition, such as memory.

Executive abilities necessary to organize, initiate, and carry out a sequence of actions may well be among the critical skills that regulate the performance of many ADLs, particularly higher order ADLs. Higher order ADLs typically involve the operation of a tool or instrument and require more steps for successful completion than do most basic ADLs. Even a relatively simple instrumental task, such as unlocking a door, requires one to pick up a key, insert the key into the lock of the door, and turn the key until the door is unlocked. Impairments in initiating or completing any of these subtasks in the proper sequence may result in overall task failure. Poor performance does not necessarily result from difficulty in remembering how to perform this and other well-rehearsed tasks, but rather, from potential distraction by competing or prepotent stimuli in the environment (telephone or television) during the execution of a step.

Review of the physical disability literature suggests that cognitive function may play two critical roles in the detection of subclinical physical functional difficulties. First, cognitive impairment may reduce the accuracy of one's perception of everyday functional ability on self-report. For example, one may not perceive difficulty on many well-practiced everyday activities if not immediately confronted with the consequences of impaired function (e.g., forgetting to mail bills, making poor decisions while driving). This absent or delayed feedback on many higher order, everyday tasks may lead to differing thresholds in the perception of difficulty on ADL versus IADL functions. The second role that cognition may play in physical function is through age-associated declines in executive abilities, which may mediate the onset and progression of impairment on cognitively demanding, everyday tasks of daily living. The dual effect that cognition may play on both self-reported and actual physical test performance highlights the need to use performance-based measures to directly assess the association of cognition and physical function.

We assessed the association of cognition and physical function in the Women's Health and Aging Study II, a cohort selected to be representative of the least disabled two-thirds of 70–80-year-old, community-dwelling women, with the goal of gaining insight into the etiology and precursors of physical functional disability. This study examined their neuropsychological test performance across multiple cognitive domains to assess whether executive attentional abilities were uniquely associated with performance on comprehensive measures of IADL versus ADL test performance. Cognitive, IADL, and basic ADL functions were assessed using a battery of timed, performance-based tests in order to optimally characterize the range of functions at higher levels of ability. Use of continuous, time-based rather than binary (or ordinal) measures of function allowed for more precise examination of patterns of association between cognition and physical functional test performances prior to the onset of frank cognitive and physical difficulties.

Methods

Subjects

The Women's Health and Aging Study II (WHAS II) is a prospective study of physical functioning in a cohort selected from the least disabled two-thirds of 70–80-year-old, community-dwelling women in eastern Baltimore, Maryland. Its primary aims are to improve methods for detecting early disability and, ultimately, to prevent disablement. WHAS II was selected to complement the WHAS I, a study of the one-third most disabled, community-dwelling older women in eastern Baltimore (Fried, Kasper, Guralnik, & Simonsick, 1995). The sampling frame for the WHAS II was based on the same survey population as selected for the WHAS I, and was drawn from female Medicare beneficiaries on the Health Care Financing Administration (HCFA) Medicare eligibility lists who resided in 12 zip code areas in the eastern half of Baltimore City and County. For WHAS II, age-stratified (70–74, 75–79) random samples were drawn by Westat, Inc. (Rockville, MD) in three serial replicates from HCFA lists as of March 1, 1994, October 1, 1994, and May 1, 1995, with additional sampling at each replicate for individuals aging into eligibility or moving into the sampling frame (see Figure 1).

To determine eligibility for the WHAS II, trained interviewers administered a screening questionnaire. The first serial replicate was screened in person; the latter two replicates were screened by telephone because of cost constraints. Telephone screening led to lower response rates (approximately 60%) than did in-person screening (73%), with an overall response rate of 64%. This overall rate is comparable to the national average of 62% (Proceedings of the American Statistical Association Section on Survey Research Methods, 1997). Women were eligible for screening if they were aged 70–80 years as of the sampling date; could be contacted by telephone; had sufficient hearing to understand questions posed on the telephone; had sufficient proficiency in English to be interviewed; and were able to leave their home and travel to Johns Hopkins Hospital in east Baltimore for the examination. Of the 3,592 eligible women, 2,541 (64%) agreed to be screened for participation in the WHAS II. To participate in the WHAS II, each person had to achieve a score >23 out of 30 on the Mini-Mental State Exam (MMSE), a screening measure that assesses attention, verbal memory, language, and constructional praxis. Individuals were also eligible to participate if they reported no diffi-

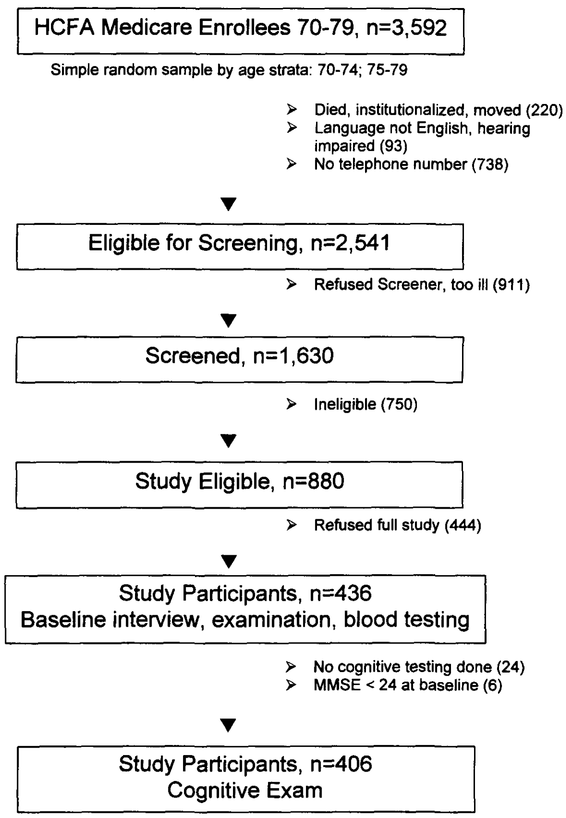

Figure 1. Sampling and recruitment design and results for the Women's Health and Aging Study II.

culty on 15 tasks of daily life, or reported difficulty in only one of the following four domains into which the 15 tasks were grouped: (a) mobility and exercise tolerance (e.g., walking one-half mile); (b) upper extremity abilities (e.g., lifting and carrying10 pounds); (c) higher functioning tasks (e.g., shopping), and (d) basic self-care (e.g., bathing; Fried et al., 1995). Using these screening criteria, 750 (46%) became ineligible. Among the eligible, screened women, 436 (49.5%) agreed to participate in the full-day evaluation at the Johns Hopkins Hospital and to prospective follow-up. Those agreeing to participate were more highly educated and had more diseases than those who refused to participate, but did not differ significantly in racial group composition, MMSE scores, or in self-reported physical difficulty (p's > .10). Of the 436 women participating in WHAS II, 24 were unable to complete the cognitive test battery because of time and scheduling constraints (5.5%), and 6 (2.8%) were eliminated from this analysis because their MMSE score on retesting in the clinic was 23 or less. Analysis of MMSE scores from subjects who failed to complete the cognitive battery (M = 28.0) revealed that they did not differ significantly from the remaining participants (M = 28.1; p > .10), suggesting that they were not selected out based upon their level of cognitive function.

Materials and Procedure

All women who participated gave informed consent and completed an interview and examination at the Johns Hopkins Functional Status Laboratory. The full-day evaluation included a health questionnaire asking participants whether they had been diagnosed as having any of the following chronic conditions or diseases: hypertension, myocardial infarction, congestive heart failure, stroke, diabetes, arthritis, cancer, lung disease, a fractured hip, Parkinson's disease, and vision or hearing difficulties. As in other studies of healthy aging (Albert et al., 1995; Seeman et al., 1994), the number of chronic diseases reported was used as a summary measure of general medical health.

Participants also received a standardized assessment of physical (Fried et al., 1991, 1995; Guralnik et al., 1994) and cognitive functioning. Performance-based measures were administered in a standardized manner by trained physical and occupational therapists who recorded times (to 0.1 seconds) required to walk 4 meters, climb up and down a set of 13 stairs, both at one's usual pace (Fried et al., 1995), and to dress, or put on a pair of pants. This last task required a subject to take off her shoes and put on a pair of loose-fitting pants (surgical "scrubs") over her clothing, unsupported, at her usual pace, thus constituting a functional balance test as well as a performance of dressing task. Test–retest reliability for the former two tasks is high, with correlations of over 0.60 for repeated measures of walking speed (Ferrucci et al., 1996). All three ADL tasks were significantly correlated with each other (r's > .40; p's < .05).

A trained occupational therapist recorded times to perform standardized instrumental functions, specifically: inserting a key into a deadbolt lock on a door and unlocking it, removing a plug from one socket and reinserting it into another outlet, and looking up and dialing a seven-digit phone number. The lock and plug tasks were significantly correlated with each other (r = .29, p < .05), and the phone task was marginally correlated with the lock task (r = .19; p < .07). Each has been used in other large-scale epidemiologic studies of aging, such as the WHAS I, the Established Populations for Epidemiologic Studies of the Elderly (EPESE), the National Health and Nutrition Examination Survey (NHANES), and the Cardiovascular Health Study (CHS).

Cognitive testing by a trained technician consisted of initial evaluation of global cognitive function using the MMSE. Remaining tests were later administered as part of a half-hour-long battery. All tests were administered according to standard procedures (see Spreen & Strauss, 1991) and will be described briefly in the order administered. Tests were ordered in such a way as to ensure appropriate, filled delays for verbal and spatial recall measures, and to maintain subject confidence by distributing more and less perceptually challenging tasks evenly throughout the session. The revised Hopkins Verbal Learning Test (HVLT-R; Brandt, 1991) assessed immediate recall, delayed recall, and recognition memory by requiring subjects to learn an auditorily presented 12-word list over three successive trials (highest score = 36). After a brief delay, as many of the 12 words as possible were to be recalled and subsequently recognized from among 24 words. The Hopkins Attention Screening Test (HAST) measured temporal sequencing ability by requiring one to reproduce a random series of lights yoked with tones presented across four corners of a hand-held game. The subject began each of three trials by reproducing one lighted tone, which was then followed by that lighted tone plus a new lighted tone, and so on, until the subject could no longer accurately reproduce the ascending sequence of lighted tones. The trial on which participants accurately reproduced the maximum number of lighted tones was then used.

The Trail Making Test (TMT; Reitan, 1958) measured two component abilities and is composed of two timed parts, A and B. On Part A, participants connected randomly arranged numbers into an ascending numeric sequence as quickly and accurately as possible. On Part B, randomly arrayed numbers and letters were to be connected in an ascending alpha-numeric sequence (1-A, 2-B, 3-C, etc.). Part A measured psychomotor and simple visual search speed, and provided a control for Part B, which additionally assessed planning, organization, and attentional flexibility. Immediate and delayed spatial learning and memory were assessed by the Hopkins Board Test (HB). On this test, participants tried to reproduce the exact arrangement of nine common objects (e.g., eye, sun, and flower) on a 3 × 3 grid by placing each object, one at a time, on the board and receiving feedback as to its correct location. To learn the arrangement to criterion, the subject needed to successfully place all nine objects on two consecutive trials. The maximum number of trials allowed was 10, and the maximum number of placement errors made over these two trials was 16; both provided measures of spatial learning. Following a delay, subjects were asked to recall as many of the nine objects as they could remember and then to place the objects in their correct locations on the board. Both the HAST and the HB test were developed to examine cognitive abilities in those with limited formal education and to require little command of the English language. Finally, auditory divided attention and working memory were assessed using the Brief Test of Attention (BTA; Schretlen, 1998), which required the subject to keep track of the number of letters or numbers presented in 10 tape-recorded sequences of letters and single-digit numbers (highest score = 10).

Results

Demographic and functional characteristics for the 406 participants at baseline evaluation are presented in Table 1. This cohort of women averaged 74 years of age, and most had achieved a high school education. A significant proportion of participants (16.7%) were African American. Participants reported an average of three chronic diseases. Functional difficulty was most often reported in the domain of mobility and exercise tolerance-demanding activities, particularly, walking one-half mile (12.8%). In the domain of upper extremity functions, difficulty was most often reported for lifting and carrying 10 pounds (4%). Difficulties in self-care ADLs and in higher-functioning IADLs, such as shopping and driving, were negligible (<1%). The remainder of the cohort reported no difficulty on these tasks.

Means, standard deviations, and ranges for IADL and ADL performance measures of physical function and for cognition are presented in Tables 2 and 3, respectively. The range and variability observed in ADL task performances was expected, given the number of women reporting difficulty in the domain of mobility. However, the great variability in IADL test performances was noteworthy given that less than 1% of women reported difficulty in this higher functioning domain. To maintain consistency across test scores during analysis, all timed scores were transformed into measures of speed (1/time) so that better performance was always positive. Comprehensive summary measures of IADL and ADL functions were derived by summing scores for standardized speeds on the three IADL tests

Table 1. Mean Demographic and Functional Characteristics (and standard deviations) of 406 High-Functioning, Older Women Participating in the Women's Health and Aging Study II

Characteristics	*M (SD)*	Range
Age	73.9 (2.8)	70–80
Education	12.6 (3.3)	2–18
MMSE	28.9 (1.6)	24–30
Race (African American)	16.7%	—
No. of chronic diseases	2.9 (1.4)	0–8
Functional domains in which difficulty was reported:		
Mobility/exercise tolerance	31.3%	
Upper extremity	8.6%	
Higher functioning	0.5%	
Self-care	0.5%	

Note: MMSE = Mini-Mental State Examination.

Table 2. Mean Times (and standard deviations) to Perform Tests of Instrumental and Basic Activities of Daily Living (ADLs) for 406 Participants in the Women's Health and Aging Study II

	M (SD)	Range
Instrumental ADLs		
Locking door (sec)	4.7 (2.7)	1.5– 21.7
Dialing phone (sec)	55.6 (38.9)	12.0–248.0
Plugging into outlet (sec)	6.3 (2.5)	1.4– 30.0
Basic ADLs		
Walking 4 meters (sec)	4.2 (1.1)	0.7– 8.3
Climbing stairs (sec)	8.1 (3.2)	2.5– 47.2
Putting on pants (sec)	18.3 (13.5)	5.0–146.0

Table 3. Mean Performances of 406 Participants in the Women's Health and Aging Study II on Neuropsychological Tests Assessing the Domains of Executive Attention, Verbal Memory, and Spatial Memory

Neuropsychological Tests	*M (SD)*	Range
Executive Attention Tests		
Brief Test of Attention (10 possible)	6.5 (2.3)	0–10
Hopkins Attention Screening Test	5.3 (2.8)	0–22
Trail Making Test, Part A (seconds)	51.2 (40.4)	16.8–300.0
Trail Making Test, Part B (seconds)	138.1 (99.5)	32.3–600.0
Verbal Memory Test		
HVLT immediate recall (36 possible)	22.6 (5.1)	7–35
HVLT delayed recall (12 possible)	8.1 (2.6)	0–12
HVLT recognition (12 possible)	10.5 (2.0)	–8–12
Spatial Memory Test		
Hopkins Board no. of errors (16 possible)	10.0 (2.0)	0–12
Hopkins Board trials to criterion	5.3 (2.6)	0–9
Hopkins Board delayed object naming (9 possible)	7.5 (1.6)	0–9
Hopkins Board delayed placement (9 possible)	8.1 (1.6)	0–9

Note: HVLT= Hopkins Verbal Learning Test.

(phone, lock, and plug) and the three ADL tests (walk, stair climb, and dress).

Because the primary aims of the WHAS II study were to examine precursors of physical functional decline, the cognitive battery was administered only after physical function tests and questionnaires were completed and, thus, was occasionally subject to incomplete data collection. Those tests administered near the end of the session were most often incomplete, resulting in a 3% loss of data points on the BTA and a 7% loss on the HB delayed naming and spatial recall variables. In order to minimize possible bias associated with excluding subjects with missing data, mean scores on a given cognitive test were imputed onto a subject's missing score. The mean cognitive test performances of those subjects with missing scores were within normal limits using age-adjusted standardized norms, where available, and not significantly different from the majority of subjects with complete data. Overall, individual scores reflected a wide range of abilities in those whose global cognitive functioning was normal as assessed by the MMSE.

Derivation of Cognitive Factors

The first step in examining the predictive utility of cognitive tests was to use factor analysis to explore whether the resulting factor structures underlying the cognitive battery conformed to anticipated domains of verbal memory, spatial memory, and executive attention. The resulting test structure was also used to guide the clustering of test variables for hierarchical regression analysis. Thus, scores for the 11 measures listed in Table 3 were entered into a maximum likelihood factor estimate. This method of factor estimation was selected over standard principal components analysis because it allowed us to test whether the optimal number of factors was used to account for the data (Harman, 1976). Maximum likelihood estimates of the factor loadings initially yielded a five-factor solution that was marginally significant because of the large sample size and the small number of common factors, but provided little additional insight beyond that of the more parsimonious, four-factor solution (Johnson & Wichem, 1992). The four-factor solution, presented in Table 4, accounted for 61.3% of variance in cognitive test performance. The first factor, Executive Attention, was composed of the BTA, the HAST, and the TMT, Parts A and B. Factor 2, labeled Verbal Memory, contained HVLT measures of immediate recall, delayed recall, and recognition. The third factor, Spatial Learning, represented the number of trials to criterion performance and the number of placement errors on the HB test. The fourth factor represented general delayed memory because it contained both verbal and spatial delayed recall variables on the HB test.

Table 4. Factor Loadings From Maximum Likelihood Factor Analysis of 11 Cognitive Test Variables in the Women's Health and Aging Study II

TestVariables	Factor 1: Executive Attention	Factor 2: Verbal Memory	Facor 3: Spatial Learning	Factor 4: General Memory
Brief Test of Attention	**0.479**[a]	0.217	0.00	0.00
Hopkins Attention Screening Test	**0.523**	0.163	0.143	0.155
Trail Making Test, Part A	**0.69**	0.142	0.00	0.143
Trail Making Test, Part B	**0.894**	0.194	0.1	0.00
HVLT immediate recall	0.384	**0.663**	0.103	0.131
HVLT delayed recall	0.236	**0.95**	0.141	0.145
HVLT recognition	0.168	**0.532**	0.215	0.146
Hopkins Board no. of errors	0.147	0.206	**0.907**	0.171
Hopkins Board trials to criterion	0.165	0.164	**0.728**	0.102
Hopkins Board delayed object naming	0.16	0.2	0.00	**0.698**
Hopkins Board delayed placement	0.137	0.00	0.288	**0.755**
Proportional variance	0.191	0.17	0.142	0.11
Cumulative variance	0.191	0.361	0.503	0.613

[a]Variables within a common factor (bolded) were highly correlated among themselves and not well correlated with variables among different factors.

Demographic Predictors of Physical Function

Using hierarchical regression analyses, demographic and chronic disease variables were entered prior to cognitive predictors. Demographic factors such as age, education, and race have been previously shown to impact on physical test performance (e.g., Berkman, Seeman, Albert, & Blazer, 1993; Seeman et al., 1994) and were expected to predict unique variance here. Age, education, race, and number of chronic diseases were regressed onto summary scores of IADL and ADL test performance. Analyses showed that age, education, and race were significantly associated with the performance of ADLs, whereas only age and race were associated with IADLs (see Table 5). Specifically, increasing age, lower education, and African American race were associated with poorer test performances. Although African American participants were generally less well educated than European American participants (11.6 vs 13.0 years, respectively), race still accounted for unique variance after adjusting for the effects of education. The limited age effects are likely due to the constrained age range sampled (70–80 years). The absence of associations between number of chronic diseases and both physical functions indicated that this marker of general medical health did not exert a strong influence on physical test performance in this high-functioning cohort.

Cognitive Predictors of Physical Function

Having adjusted for demographic and disease variables, the purpose of hierarchical regression analyses was to examine those cognitive abilities most associated with ADL and IADL test performance in the following two ways. First, latent cognitive factor scores were entered in the same order they were derived on factor analysis (Model 1). This ordering conformed to our hypothesis that Executive Attention (Factor 1) would account for the greatest amount of normal, age-related variance in the performance of higher order physical functions. Verbal Memory (Factor 2) was entered next, as it has proven most sensitive in the early detection of AD and may represent the effects of prodromal AD on physical functioning. The remaining two factors—Spatial Learning (Factor 3) and General Memory (Factor 4)—were then entered. In a second set of regressions (Model 2), all manifest cognitive test variables were entered in blocks according to the latent factors on which they loaded to determine which variables captured the most variance. The purpose of this latter analysis was to assess the potential predictive value of specific tests, which may then be applied to large-scale,

Table 5. Hierarchical Regression Analyses of Demographic Variables, Latent Cognitive Factor Scores (Model 1) and 11 Cognitive Test Variables (Model 2) on Summary Measures of Performance in Instrumental and Basic Activities of Daily Living (ADLs)[a]

	Instrumental ADLs			Basic ADLs		
	Beta Coefficient	Standard Error	variance[b]	Beta Coefficient	Standard Error	variance[b]
Demographic Variables						
Age	–0.130	0.035	0.036**	–0.119	0.040	0.022*
Education	0.055	0.032	0.049**	0.087	0.036	0.043*
Race	–1.110	0.277	0.063**	–0.635	0.314	0.019*
Number of chronic diseases	–0.030	0.068	0.002	–0.050	0.077	0.002
Model 1: Latent Cognitive Factors						
Executive attention	0.640	0.111	0.066**	0.250	0.128	0.010*
Verbal memory	0.058	0.093	0.001	–0.030	0.109	0.000
Spatial learning	0.100	0.096	0.001	0.236	0.112	0.010*
General memory	0.074	0.109	0.001	–0.036	0.125	0.000
Multiple R^2			0.219			0.106
Model 2: Cognitive Test Variables						
Trail Making Test, Part A	0.002	0.004	0.012	–0.006	0.004	0.005
Trail Making Test, Part B	–0.004	0.00	0.02*	0.001	0.002	0.001
Brief Test of Attention	–0.027	0.047	0.000	0.049	0.054	0.004
Hopkins Attention Screening Test	0.044	0.040	0.005	0.016	0.045	0.001
HVLT immediate recall	0.028	0.031	0.002	0.015	0.034	0.000
HVLT delayed recall	–0.002	0.065	0.000	–0.076	0.074	0.000
HVLT recognition	–0.063	0.060	0.002	0.080	0.068	0.004
Hopkins Board no. of errors	0.049	0.074	0.002	0.237	0.084	0.008**
Hopkins Board trials to criterion	–0.001	0.053	0.000	–0.107	0.059	0.008
Hopkins Board delayed object naming	–0.002	0.078	0.000	0.011	0.088	0.000
Hopkins Board delayed placement	0.015	0.078	0.000	–0.116	0.089	0.005
Multiple R^2			0.193			0.122

*$p < .05$; **$p < .01$.
[a]Regression models were adjusted for demographic and disease variables.
[b]Incremental variance in the outcome variable explained by each independent variable when entered sequentially.

epidemiologic studies and to geriatric settings where clinicians must select one or two tests with easily interpretable results.

Hierarchical regression of latent cognitive factor scores on IADL test performance revealed that Factor 1, Executive Attention, was the single most significant predictor of performance, accounting for almost 7% of incremental variance on sequential analysis of variance (ANOVA; see Table 5). Including demographic variables, the regression model accounted for 21.9% of variance in this high-functioning cohort's IADL test performance. The second regression, using all cognitive test variables, showed that the highest-loading Executive Attention measure, Part B of the Trail Making Test, was the only significant cognitive predictor. On sequential ANOVA, it accounted for 2.0% of incremental variance in IADL performance after adjusting for age, education, race, chronic disease, and Part A of the Trail Making Test. Part A of the Trail Making Test was entered before Part B to assess the effect of psychomotor speed and did not account for significant variance. This result suggested that the mental flexibility component unique to Part B accounted for the majority of attentional variance. Having determined that simple psychomotor speed did not account for significant variance in IADL performance when entered by itself, we then partialed out the effect of Part A on Part B by using a difference score (Parts B–A). It was entered into the regression, above, in place of the two individual measures and accounted for 2.7% of variance in IADL performance; no other cognitive test measure approached significance.

Hierarchical regressions examining the association of cognitive factors on ADL test performance showed that Executive Attention and Spatial Learning were significant predictors. On sequential ANOVA, each accounted for 1% of incremental variance. Overall, the regression model accounted for half as much variance in ADL (10.5%) as IADL test performance (22%), and two cognitive domains accounted for just 2% of the explained variance. When using all 11 cognitive test variables, only the Spatial Learning measure, the HB number of placement errors was significant ($p = .0048$), while HB trials to criterion was only marginally significant ($p = .0693$). Each accounted for less than 1% of incremental variance in ADL test performance. No Executive Attention tests accounted for significant variance.

Executive Attention in Poor IADL Test Performers

To capture in practical terms how executive functions varied in those with better versus poorer IADL abilities, and how this performance compared to other healthy older adult samples, we divided the cohort into quartiles according to their overall IADL performance scores. We then compared those in the lowest ("low performers") and the highest ("high performers") quartiles on the critical measure of executive function, the Trail

Making Test. Low performers were approximately 28 seconds slower ($M = 65.9$; $SD = 54.8$) than high performers on Part A ($M = 38.3$; $SD = 12.5$) and over 87 seconds slower ($M = 185.4$; $SD = 131.1$), on average, than high performers ($M = 97.7$; $SD = 36.5$) on Part B. Finally, comparison of high performers' mean time to complete Part B with age-appropriate norms (Mayo's Older Americans Normative Study; Ivnik et al., 1996) demonstrated that they were performing at about the 50th percentile. A similar comparison of low performers placed them below the 15th percentiles on Parts A and B, suggesting that they were performing poorly relative to other older adult cohorts as well.

Discussion

This study found that executive tests of planning, organization, and flexibility were selectively associated with the performance of IADLs in a physically high-functioning, cognitively intact, community-dwelling sample of older women. Executive attention was associated with more variance in complex functional activities (e.g., using the telephone) than were other cognitive tests of verbal and spatial memory; the former accounted for almost 7% of incremental variance after adjustment for demographic and disease factors. In particular, Part B of the TMT accounted for the greatest proportion of explained variance, whereas the component of the TMT that controls for psychomotor speed (Part A) was not significant. These findings suggest that mental flexibility, rather than fine motor agility, is the attentional component critical to efficiently completing many complex, everyday activities. Nevertheless, cognitive test performance explained a relatively small amount of IADL test variance, perhaps because the cohort was screened by the MMSE and self-selected to be cognitively high functioning (participants had more education than refusers). The screening criterion ensured that participants were generally free of clinical dementia at baseline assessment, so that cognitive decline and incident difficulty could be examined in relation to subsequent physical function. As these high-functioning individuals age, the role of executive functions on everyday functioning is anticipated to become more important.

Other research has shown that measures of general mental status (e.g., MMSE) are associated with disabled adults' concurrent difficulty in IADLs, independent of chronic disease (e.g., Fried et al., 1995; Richardson et al., 1995), but this study takes two additional steps toward understanding how cognition may influence physical functions. First, we found that cognitive abilities were associated with performance-based difficulties *in the absence of* (or prior to the onset of) cognitive and physical disability. Second, we specified the domain of cognition that appeared to be most associated with the performance of IADLs. Executive attentional difficulties in planning, initiating, and sequencing information appeared to be more important than memory in carrying out some higher order physical functions. Although the associations of cognition with physical functions are of moderate size in this cohort, these results may have prognostic value in the majority of older adults who report little or no frank disability, and yet exhibit a wide range of abilities in performing higher order functions.

On mobility-based ADLs, executive and spatial learning abilities collectively accounted for only 2% of the 10% of explained variance in ADL test performance. When individual tests were considered, only spatial learning played a nominally signficant role. The basis for this association is presently unclear. These results generally agree with earlier outcomes in geriatric patient populations by showing that a variety of cognitive abilities predicted little variance in basic ADL functions. Furthermore, even demographic variables typically found to be important predictors of basic ADL function, including age, education, and race (e.g., Albert et al., 1995; Berkman et al., 1993; Pinsky, Leaverton, & Stokes, 1987), only explained a modest amount of performance-based variance (8% collectively) in these high-functioning participants. Associations were similar to that of other studies such that being younger, having more education, and being European American were all associated with better mobility-based ADL test performance.

The selective association of executive attention with IADL function over verbal and spatial memory abilities indicates that those cognitive domains associated with subclinical physical functional difficulties in community-dwelling populations are somewhat distinct from the memory deficits typically associated with compromised everyday function in dementia patients. The most common form of dementia, Alzheimer's disease (AD), is characterized by progressive memory loss resulting from pathological deterioration of the hippocampus. Such memory loss may be expected to predict difficulties in everyday function in these patients. However, the predictive utility of executive abilities in a nondemented cohort may highlight the functional consequences of nonpathological, age-related brain changes in frontal lobe function. Most age-related brain changes occur in the frontal cortex, an area associated with executive attention in numerous human (Lezak, 1995; Stuss & Benson, 1984) and nonhuman, primate studies (Fuster, 1989; Krasnegor et al., 1997). These changes are small, variable, and progressive, and may play a significant role in hastening the progression of subclinical functional difficulty.

Limitations of the Study

Three potential limitations of this study are considered. The first limitation regards the combination of two relatively simple tasks (key into lock, plug into outlet) with a more complex task (looking up and dialing a telephone number) to derive a comprehensive, conceptual measure of IADL function. Because correlations among these three IADL tasks were weaker than were associations among the three ADL tasks, we considered whether only the telephone task was associated with executive attention. We thus conducted separate hierarchical regression analyses on the telephone task alone and on the lock and plug tasks alone. Results were similar to that when using the single composite measure; the executive attention factor and, specifically, Part B of the Trail Making Test accounted for the greatest proportion of variance on both measures. On the telephone task alone, the delayed recall component of the Hopkins Verbal Learning Test additionally became significant. This potential association between verbal memory and more complex IADL function will be explored in follow-up investigations of the WHAS II cohort as other complex IADL measures (medication taking and meal preparation) are now being used.

A second potential limitation of this study lies in the generalizability of findings of predictive associations in this cohort beyond populations whose demographic characteristics match this study. Because we were primarily dependent on telephone screening for recruitment of the cohort, recruitment rates were substantially lower than would be desirable for a population-based, representative study, and lower than what can be achieved using in-home recruitment. Among those screened, study participants and refusers were comparable in reported level of physical difficulty, MMSE score, and racial group composition, but participants had a greater number of chronic diseases and were more highly educated than refusers, thereby requiring that all analyses adjust for these variables. Unfortunately, it is not possible to determine the characteristics of those who refused screening in this study. However, the association observed between executive abilities and instrumental functions in this highly educated cohort probably represents a conservative estimate relative to that in more educationally diverse samples, whose cognitive test performance is typically more variable. A more significant limitation stems from the cross-sectional nature of this study, which presently does not allow us to determine whether difficulties in executive function predict subsequent difficulties in IADL function. Assessing the direction of this association remains an important basis for prospective study in the WHAS II. Results of such prospective study will guide more extensive investigation of the etiology and preclinical treatment of these changes.

Methods that assist in identifying and treating individuals in subclinical stages of disability are key, particularly when considering that many older adults reporting no functional disability nevertheless experience mild functional loss (Fried et al., 1996; in press). Additional support for this view comes from self-report data in this study. Despite participants' greater reports of difficulty in mobility-based physical functions (31%) relative to instrumental functions (<1%), the range of physical test performances suggested that a number of participants were approaching clinical levels of difficulty on the most complex IADL function, looking up and dialing a telephone number. This seeming discrepancy between self-reported and actual performance-based difficulty may reflect differing thresholds in the perception of difficulty on ADL versus IADL functions. Or, perhaps this discrepancy reflects the role that cognition plays on one's awareness of, or insight into, her own cognitive limitations. As noted earlier, patients in the early stages of a progressive dementia often lack insight into the severity of their cognitive difficulties. Thus, the very mechanisms associated with physical functional impairment may also be associated with the under-identification of such impairment using traditional self-report methods. In either event, these results highlight the need to go beyond self-report measures to develop prognostic tools that accurately identify individuals at risk of clinical impairment on IADLs. The results of this study preliminarily suggest that the Trail Making Test, or related executive attention measures, may increase sensitivity in detecting subclinical deficits in complex, everyday functions.

Understanding whether executive attentional difficulties lead to subsequent clinical difficulties in carrying out instrumental activities will allow us to better devise interventions that effectively delay or prevent the onset of such clinical disability. To delay the physical functional consequences of executive impairments, patients may be taught to use environmental aids, many of which have been successfully developed to treat other patient groups with executive deficits, often resulting from traumatic head injury. These aids may include the reduction of environmental distraction (e.g., turning off television) and the use of timers and color-coded cue cards to sequence steps during meal preparation. Although individuals may resist or be unable to acknowledge functional limitations, they may readily use these aids in order to maintain their functional independence. From a prevention perspective, this and other work (Grigsby et al., 1998) provide preliminary support for the importance of executive functions and their maintenance in older age. Models of prevention through maintenance have been useful in the domain of physical function (e.g., Mor et al., 1989). They have also shown that regular physical activity helps to maintain levels of cerebral blood flow (Rogers, Meyer, & Mortel, 1990) and cognitive test performance (Dustman et al., 1990; Rogers et al., 1990), perhaps because many physical activities are also cognitively demanding (e.g., driving and volunteering). These data, when taken with our findings, preliminarily suggest that participation in cognitively stimulating activity may help maintain executive and higher order physical functions as adults age.

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