Gerontology

Behavioural Science Section

Gerontology 2005;51:131–141
DOI: 10.1159/000082199

Received: October 10, 2003
Accepted: May 24, 2004

Sensory and Cognitive Factors Influencing Functional Ability in Older Adults

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Key Words

Cognitive aging · Processing speed · Everyday abilities · Mobility

Abstract

Background: Age-related sensory and cognitive impairments have been related to functional performance in older adults. With regard to cognitive abilities, processing speed in particular may be strongly related to older adults' abilities to perform everyday tasks. Identifying and comparing cognitive correlates of functional performance is particularly important in order to design interventions to promote independence and prevent functional disability. ***Objective:*** The present study examined the relative importance of cognitive (specifically, speeded and nonspeeded) and sensory factors in relation to older adults' functional abilities. Functional abilities included measures of mobility and performance of everyday activities. ***Methods:*** A cross-sectional study design was employed. Five hundred and thirty adults between the ages of 62 and 94 completed measures of sensory, cognitive (including processing speed, attention, memory, intelligence) and functional abilities. ***Results:*** Overall, functional performance was most strongly associated with cognitive speed performance, but nonspeeded cognitive and sensory abilities also accounted for significant amounts of variance in functional performance. Age explained a small but statistically significant amount of additional variance in some functional abilities, but no additional variance in self-reported mobility measures. ***Conclusion:*** These findings point to the potential impact of multifaceted training programs, targeting both sensory and cognitive abilities for maintaining functional abilities.

According to projections by the United States Census Bureau, by the year 2050, up to 20% of the total United States population will be aged 65 and older [1]. While many people experience healthy aging without significant impairments, a number of sensory, cognitive and functional declines can occur with age, threatening independence. In cases of extreme sensory or cognitive loss, the capacity to perform activities of daily living (ADLs; e.g., toileting, eating, bathing and very basic aspects of mobility) can be compromised [2, 3]. However, older adults can experience less visible but equally damaging losses in the ability to perform instrumental activities of daily living (IADLs; e.g., balancing a checkbook, grocery shopping, medication management and driving) [4, 5]. Considering the population trends and the changes that occur with aging, there is increasing concern that as the percentage of older adults in the general population rises, there will be a growing number of older adults who cannot function independently. There are high economic costs, both direct (e.g., subsidizing nursing home care, medical treatment costs of preventable accidents such as falls or crashes) and indirect (e.g., lost productivity of family

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caregivers), when older adults can no longer live independently [6]. Therefore, the identification of cognitive and sensory risk factors that jeopardize functional capacities is a pertinent topic for aging research.

The purpose of the present paper is to identify and compare factors that are strongly associated with functional performance difficulties, which can account for the wide variability in function among older adults, and could be targeted for intervention. Specifically, the relation of cognitive abilities, speed of processing in particular, and sensory function to functional performance and self-reported mobility will be examined.

Everyday Functional Performance and Aging

As people age and experience changes in sensory and cognitive abilities, they may also tend to experience declines in the ability to carry out everyday activities required to remain independent and healthy [7–11]. Mobility is a particularly important functional ability that can be impaired with age [12, 13] and encompasses a range of abilities, from simply being able to move one's body, to the extent of one's life-space and driving-space, to the avoidance of negative outcomes such as falls and automobile crashes [12, 14, 15]. For example, many older drivers reduce their driving in order to avoid potentially dangerous or bothersome driving situations such as driving at night, in the rain or during rush hour [16–18]. Such changes in driving habits, in particular driving cessation, are a threat to maintaining independence and also may lead to adverse consequences such as depression and less access to resources such as healthcare [12, 19, 20]. Negative mobility outcomes, as measured by rates of traffic convictions, crashes and fatalities per mile driven, are also higher among older drivers than any other age group [14].

Sensory Status and Functional Performance

Sensory abilities have been related to a number of aspects of functional performance. For example, West et al. [21] found that many measures of visual ability were associated with decreased physical functioning. Ball et al. [16] found that visual function correlated with increased driving avoidance behaviors. Similarly, drivers with cataract have been found to be more likely than older adult drivers without cataract to drive slowly, be advised to stop driving, prefer that someone else drive, and limit their own driving exposure [22]. In a population-based study, contrast sensitivity was found to be significantly correlated with all, and far visual acuity to be significantly correlated with most of the study's performance-based measures of functional abilities [23]. Visual acuity and contrast sensitivity also have been related to performance of IADLs [24]. In a one-year longitudinal study of over 2,000 community-dwelling older adults, Wallhagen et al. [25] found that both impaired vision and impaired hearing were related to poorer performance of ADLs and IADLs. Along the same lines, among older adults in the Berlin Aging Study, both vision and hearing predicted measures of Basic Competence and Expanded Competence, which are similar to ADLs and IADLs [26].

Cognitive Abilities and Functional Performance

Age-related declines are also well documented in several aspects of cognitive functioning and contribute to deterioration of abilities to carry out everyday tasks. For example, memory difficulty is related to slower performance of timed IADL tasks [27]. Memory, along with intellectual functioning, is also related to performance on the Everyday Cognition Battery, which measures the relationships between cognitive abilities and real-world functional measures [28]. Fluid reasoning is predictive of everyday task competence [11] and is also related to performance of timed IADLs [27]. Executive function has been found to significantly predict performance of IADLs [29]; moreover, executive function has been found to be a better predictor of IADL performance than depression, demographic factors or other aspects of cognition in older adults [30].

Recent evidence suggests that cognitive speed in particular may be strongly related to functional abilities [31, 32]. For example, UFOV®[1] measure of processing speed is significantly related to several measures of functional abilities in older adults. UFOV significantly predicts the ability to carry out IADLs [24, 27] and mobility outcomes such as crash rates [8, 33], driving avoidance [16] and limited life-space [15].

The present cross-sectional study examined a large group of older adults with a broad range of sensory and cognitive capacities and diverse health status. A variety of aspects of everyday functioning were measured in order to explore in concert the relationships among various

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sensory, cognitive and functional abilities, and to examine the capability of sensory and cognitive abilities to account for variance in functional performance among older adults. The study was designed with the goal of measuring cognitive and sensory abilities across many modalities, enabling the creation of constructs, which should be more stable than specific measures in predicting functional outcomes. Of particular interest was the relative importance of sensory and cognitive abilities to the functional performance of older adults, and the identification of which abilities are most strongly related to specific functional tasks and therefore promising targets for intervention. It was hypothesized that speed of processing abilities would be most strongly associated with functional outcomes, followed by other cognitive abilities and sensory status. Furthermore, it was hypothesized that age would explain very little variance in the functional outcome measures once cognitive and sensory abilities were accounted for, suggesting that interventions which effectively improve these abilities may be effective for reducing or eliminating aging-related decrements in functional abilities.

Methods

Participants

Participants were recruited in Bowling Green, Ky., and Birmingham, Ala., and surrounding areas from a variety of sources including community-dwelling individuals who responded to a mass-mailed information letter, were previously screened for other university-affiliated research projects, or were referred by other research participants. All participants in the present study are part of a larger, ongoing study, 'SKILL – Staying Keen in Later Life'. This study aims to examine the relations among cognitive, sensory and functional abilities in older adults, and to evaluate the impact of cognitive training upon cognitive and functional performance for older adults with speed of processing impairments. At the point of data extraction, 530 adults between the ages of 62 and 94 years had completed the baseline phase of the study. Eighty individuals who came in for screening failed to complete the subsequent baseline visit; 10 were ineligible and 70 refused further participation. The participants were mostly women (60% female) and Caucasian (90.3%; 9.4% were African American and 0.2% were of another race). The education level of the sample ranged from 7th grade (0.2%) to doctoral (3.6%), and the average educational attainment was 'some college or vocational training after high school graduation'. Seventy percent of older adults in the United States have an education level of high school graduation or above [34], whereas our sample is somewhat more educated, with 92% having a high school degree or beyond. The mean Mini Mental State Exam (MMSE) score of participants was 28.29 (SD = 1.93). Although no potential participant was excluded on the basis of MMSE score, only one participant reported having a diagnosis of dementia.

Adults 60 years of age and older were eligible for screening. A minimum far visual acuity score of 20/80 (with the participant's corrective lenses when applicable) and a demonstration of literacy at the 5th grade level were required for inclusion. These criteria were selected as the minimum abilities needed to see and read stimuli involved in the test battery. Inclusion criteria were kept to a minimum in order to involve a sample with a wide range of sensory, cognitive and functional capacities.

Measures

Participants completed a 1.5-hour screening visit to determine eligibility for the study and, if eligible, a baseline assessment (2.5-hour visit) of cognitive, sensory and functional abilities.

Functional Ability Measures

Timed Instrumental Activities of Daily Living

The timed instrumental activities of daily living (TIADL) [24, 27] measure everyday cognition by requiring the participant to perform a series of timed, simulated everyday activities in the laboratory. The tasks included (a) looking up and reading aloud a specified telephone number in a phone book, (b) counting out 67 cents in change from a handful of coins, (c) locating and reading ingredients from labels on 3 cans of food, (d) finding 2 specified items on a crowded grocery shelf, and (e) reading instructions from 2 prescription medication labels. Participants are instructed to wear their usual corrective lenses for reading, if any, during the test. Data are collected on performance time and accuracy for each task. The variable used in analyses was the sum of z-scores calculated for each task and thus represents performance on all 5 tasks. Test-retest reliability of TIADL is 0.64 [27].

Road Sign Test

The Road Sign Test (RST) [14] is a computerized measure of everyday cognition. It requires participants to use a mouse to react to changes in displays of road signs. The participant is instructed to watch the monitor screen for a sign without a slash through it and react immediately. Required reactions involve moving the mouse to the left (in response to a left turn sign) or right (in response to a right turn sign), or clicking a button on the mouse (in response to a bicycle sign or pedestrian sign). No reaction to signs with a red slash through them is required. Multiple road signs (either 3 or 6 at a time) appear on the screen simultaneously. As the participant watches, the signs disappear and then reappear at different locations on the monitor screen. At first, all the signs have slashes through them. Eventually, one of the signs in the display appears without a red slash through it, requiring a response from the participant. The time from the presentation of a stimulus to the performance of the correct reaction by the participant is measured. In this study, the RST score used in analyses was the average of the participant's reaction time in the 3- and 6-sign conditions. Test-retest reliability of RST is 0.56 [35].

Mobility Questionnaire

The Mobility Questionnaire (MQ) [15, 22] is a survey of many aspects of participants' mobility, including indices of (a) life-space, (b) driving-space and (c) driving exposure. In the present study, scores were calculated in the following manner. Life-space was derived from 9 questions about where the participant had been over the last 7 days or 2 months (ranging from beyond the bedroom to beyond this region of the United States). The number of positive responses was summed to create a life-space score, representing the spatial boundaries of the participant's activities. Participants were also asked 6 questions about where they had personally driven during the same time span. The positive responses were summed to create a driving-space score, representing the participant's range of driving. One additional MQ item was included as a measure of everyday functioning in this study: how many days the participant drives in an average week (driving exposure). Test-retest reliability is 0.80 for life-space [15], 0.86 for driving-space and 0.83 for driving exposure [22].

Sensory Measures

Far Visual Acuity

Far visual acuity was measured using the ETDRS Chart with a Good-Lite model 600A light box. Distance vision was tested binocularly in a darkened room at a distance of 10 ft, first without correction and then with correction, if corrective lenses were usually worn. Participants read the letters from left to right on 9 lines that become progressively smaller by the line. The ACTIVE scoring system was used [35]. According to this scoring method, each line is worth a total of 10 points, and scores may range from 0 (if no letters were correctly identified, approximately equivalent to a Snellen score of 20/125) to 90 (if all letters were correctly identified, approximately equivalent to a Snellen score of 20/16). The value used in analyses was the better score for corrected/uncorrected vision.

Near Visual Acuity

Near visual acuity was measured using the Lighthouse Near Visual Acuity Modified ETDRS chart. Near vision was tested binocularly, first without any correction and then with correction, if any. The chart was held 40 cm from the participant's eyes, unless the participant could not identify any letters at this distance, in which case a distance of 20 cm was used (testing distance was incorporated into the scoring system). Log Minimum Angle Resolvable scores were used. In this method, possible scores range from 1.30 (equivalent to a Snellen score of 20/400) to – 0.10 (equivalent to a Snellen score of 20/16), with lower values representing better performance. The value used in analyses was the better score for corrected/uncorrected vision.

Contrast Sensitivity

Contrast sensitivity was assessed binocularly (with distance correction, if corrective lenses were usually worn) at a distance of 40 in, using the Pelli-Robson Contrast Sensitivity Chart [36]. This chart consists of 8 rows of letters with 2 sets of 3 letters on each row. The contrast of the letters against the white background of the chart gradually decreases across letters as the participant reads from left to right and top to bottom. Possible scores range from 0.00 (poorest performance) to 2.25 $\log_{10}$ (best possible performance). In this study, the participant received the log contrast sensitivity score associated with the last set in which 2 of the 3 letters were correctly identified.

Hearing

Pure tone threshold hearing was measured with a GSI 17 (Grayson Stadler, Inc.) audiometer at 500, 1,000 and 2,000 Hz in the right and left ears individually. Headphones were placed over both ears of the participant, who was seated facing away from the audiometer and instructed to raise his or her hand when a tone was detected. Standard procedures for obtaining pure tone thresholds were followed. The score used in these analyses was calculated by averaging the 6 thresholds obtained.

Balance

Balance was measured with the Turn 360 test [13]. Participants were asked to assume a starting position and make 1 complete 360° turn. The number of steps required to make the turn was recorded, as was the use of any assistive device. The procedure was repeated for a second turn. Fewer steps represent better performance. The score used in these analyses was the average number of steps across both turns.

Cognitive Measures

Mental Status – Mini Mental State Exam

The Mini Mental State Exam (MMSE) [37] measures orientation, attention, memory, language and construction skills, and has been widely used to determine mental status and screen for dementia. Scores range from 0 to 30, with higher scores indicating better cognitive function.

Literacy – The Adult Dyslexia Test

A portion of the Adult Dyslexia test [38] was used as a gross screen of literacy. In this study, participants were asked to read seven 5th-grade level words. At least 4 of the words had to be correctly read to meet the literacy requirement. As described above, this measure was used as an inclusion filter, and scores were not included in analyses.

Processing Speed

UFOV. The UFOV [33] is a computerized test of cognitive processing speed that assesses the minimum display duration necessary for a participant to attend to multiple visual stimuli. The test includes 4 increasingly complex subtests. The 1st subtest requires the participant to identify a car or truck flashed briefly inside a fixation box. The 2nd subtest requires the participant to identify the central target and simultaneously notice where a car appears in the periphery. The 3rd subtest is identical to the 2nd subtest except for the addition of distractors, which makes locating the peripheral target more difficult. The 4th subtest requires the participant to determine whether 2 objects presented simultaneously at central fixation are the same (2 cars or 2 trucks) or different (1 car and 1 truck) and at the same time locate the peripheral car surrounded by distractors. For each subtest of the UFOV, the participant views the presentation of stimuli and then answers questions by touching a response choice from 2 alternatives for the central task and 8 alternatives for the peripheral task, using a touch-sensitive computer monitor. A processing speed threshold is established for each participant via a double staircase method; for each subtest, this threshold represents the display duration at which the participant correctly responds on 75% of trials. These durations can range from 16 to 500 ms on each subtest. In these analyses, the score used was the sum of the thresholds for all 4 subtests. The PC version of the UFOV test used in this study has a test-retest reliability of 0.81 [39].

Letter Comparison [adapted from ref. 40]. Participants were presented with a sheet containing 2 columns of paired letter sets and were required to determine whether or not each pair of letter sets was identical. Three different letter set sizes (3, 6 and 9 letters) were used. For each set size, participants were required to complete as many comparisons as possible in the time allotted (20 s for each of 3 sections). The score used in these analyses was the sum of correctly completed comparisons across all 3 sections.

Pattern Comparison. Pattern Comparison [adapted from ref. 40] is similar to Letter Comparison, except that line segments are used as the stimulus element rather than letters. In this study, the complexity of the patterns was varied (either 3, 6 or 9 line segments). As in the Letter Comparison task, participants were required to determine if a pair of line segments was identical. The number of comparisons correctly completed in the time allotted (20 s for each of 6 sections) was determined. The values were summed across the 6 sections.

Digit Symbol Substitution and Digit Symbol Copy. WAIS-R Digit Symbol Substitution [41] requires participants to fill in a grid of empty squares with symbols, by associating the number appearing above each square with the symbol paired with that number in a key at the top of the page. Participants must complete as many substitutions as possible in 90 s. In this study, the average number of seconds required to substitute 1 item was calculated for each participant.

Digit Symbol Copy [42] requires participants to fill in a grid of empty squares with symbols, by simply copying the symbol located above each square. There is no time limit; however, the test is timed and participants are instructed to work as quickly as possible. In this study, the average number of seconds required to copy 1 item was calculated for each participant. The Digit Symbol Copy score was then used to adjust the Digit Symbol Substitution score, thereby correcting for the time required to write each symbol (this correction factor controls for motor speed and allows a purer measure of the cognitive processing time required for making the substitution). Corrected scores were used in analyses.

Attention Switching

Shape Color Size

Shape Color Size (SCS) [adapted from ref. 43] requires the participant to use a computer mouse to make same/different judgments about the shape, size or color of 2 objects presented on the monitor screen. Participants choose whether they would like to use the right or left button on the mouse to indicate that 2 objects are the same (the other button is used to indicate 'different'). For each trial, the word 'shape,' 'color' or 'size' (the dimension to be compared) appears first in the center of the screen. Then 2 objects are presented. The participant is required to decide whether the objects are the same or different on the dimension indicated and to react as quickly as possible by clicking the corresponding button on the mouse.

In the present study, the test was given in 4 sections. In 2 of the sections, the property to be compared was random at each presentation. In the other 2 sections, the trials were blocked, so that questions about color, shape and size were each grouped together. Participants were informed prior to the start of each section whether the trials would occur randomly or in blocks. The time from the presentation of a stimulus to the reaction by the participant was measured, as well as response accuracy. The score used in these analyses was the mean reaction time for all correct responses across both conditions (SCS RT).

Lexical Decisions

Lexical decisions [Lex Dec; adapted from ref. 44] require the participant to use the buttons on a computer mouse to indicate whether a string of letters spells a real word. In the Lex Dec task, each trial begins with a cursor blinking in the center of the screen. The cursor is followed by a word in white capital letters that serves as a prime. Following the prime, the target appears in green letters with either normal spacing (for example, 'target'), blank spaces between each letter ('t a r g e t') or asterisks between each letter ('t*a*r*g*e*t'). The participant is instructed to ignore the blank spaces or asterisks and quickly decide whether the green letters spell a real word or not. The time from the presentation of the test stimulus to the reaction by the participant is measured, as well as response accuracy. The score used in these analyses was the mean reaction time for all correct responses to real words presented across all 3 conditions (Lex Dec RT).

Working Memory

WMS-III Spatial Span

Spatial Span [45] measures spatial memory by requiring the participant to observe and then imitate the tester by touching a specific series of blocks in the same order that the tester has touched them. The number of blocks in the series increases, which heightens the demand on working memory, until the participant either fails enough trials to trigger a cut-off point or completes the most difficult series. The score used in analyses was the number of series correctly replicated.

WMS-III Digit Span

Digit Span [45] requires the participant to listen and then verbally repeat a series of digits read by the tester. Each pair of series gets longer, until the participant either fails enough trials to trigger a cut-off point or completes the most difficult series. The score used in analyses was the number of series correctly repeated.

Hopkins Verbal Learning Test

The Hopkins Verbal Learning Test (HVLT) [46] requires the participant to memorize a list of 12 words read to them by the tester. Three memorization trials are given, and after each trial participants are asked to recall all of the words from the list. Following these 3 trials, participants listen to a list of 12 target and 24 distractor words and indicate whether or not the words were in the memorization list. This recognition trial is scored by a discrimination index, which is created by subtracting the number of false positives from the number of true positives. The average number of words recalled across the 3 memorization trials (HVLT avg) and the discrimination index (HVLT DI) were used in these analyses.

Intellectual Functioning

WASI Vocabulary

The Vocabulary subtest of the WASI [47] measures verbal intelligence by having participants define words. This measure taps crystallized intelligence, which is known to be relatively stable across the life span [10]. The raw score was converted to a t-score, which was used in these analyses.

WASI Matrix Reasoning

Matrix Reasoning [47] measures nonverbal intelligence by asking participants to solve a series of picture puzzles in which part of each picture is missing. Participants select the piece that would best complete the picture from 5 choices at the bottom of each page. This measure taps fluid intelligence, which is subject to decline with age [48]. The raw score was converted to a t-score, which was used in these analyses.

Executive Function

Trails A and Trails B

Trails A and B [49, 50] require participants to navigate a series of numbers (Trails A) and of alternating numbers and letters (Trails B) and connect them in sequential (A) or alternating sequential (B) order. If the participant makes a mistake, he or she is redirected to the last correct response and told to continue. The time required to complete each task is recorded. In this study, a time limit of 480 s was imposed for Trails B.

Stroop

Stroop [51–53] is a computerized adaptation of the original task that measures the time it takes for participants to (a) read a series of words that name colors (red, blue, green and yellow), (b) name the color of color blocks (also red, blue, green and yellow), and (c) name the ink color in which a series of color words appear rather than reading the words themselves (the ink color is discordant with the color words; e.g., 'red' printed in blue ink requires a response of 'blue'). In all 3 tasks, participants are instructed to correct any mistakes they make and then move on. The time it takes to complete each task is measured, as are the number of uncorrected mistakes made in the 3rd task. For the present analyses, a score was derived from the difference between the time required to complete the 3rd (ink color naming) task and the 2nd (color block naming) task, adjusted with a time penalty for the number of uncorrected mistakes made during the 3rd task.

Results

Data Treatment

Missing Data

Most participants had valid scores for all measurements (less than 1% of the data were missing). There was a small amount of missing data for some measures due to refusals, participant's inability to perform, or equipment or administrator errors. In no case was any measure missing more than 3% of the cases. When sensory and cognitive data were missing at random, imputation of data was done with maximum likelihood procedures [54]. If data were not missing at random, but rather represented a participant's inability to perform a task, the data point was replaced with a minimum score. A minimum score was either a predetermined limit for that measure (480 s for Trails B, for example) or a value of 3 standard deviations from the mean for that measure, in the direction of poorer performance. In no instance did an assigned score of 3 standard deviations from the mean exceed the range of obtained scores on that measure.

Outliers

Because of the wide range of abilities among participants, some outlying scores were obtained; the vast majority of these were in the direction of poorer performance. Outliers for the cognitive and sensory variables were constrained to a minimum or maximum score equivalent to ± 3 standard deviations from the mean. For most measures very few, if any, outliers were found (1–4 cases); HVLT DI had the most outliers with 13 cases. Functional performance and mobility measures were not constrained.

Standardization

Prior to conducting correlations, regressions and factor analyses, scores on all measures except age were converted to z-scores, and then measures on which a smaller score represented better performance were reverse-scored, so that higher scores represent better performance across measures. Means and standard deviations for all measures are presented in their original metric (prior to standardization) in table 1.

Analyses

Factor Analysis

Factor analysis was performed in order to test our conceptualization of the measures (including speed of processing, other cognitive abilities and sensory) as well as to reduce the variables to a small number of factors to be examined with respect to impact on functional performance. After using the principal components extraction method, an examination of the scree plot suggested the existence of 3 factors. A Varimax rotation with Kaiser normalization was performed, resulting in 3 factors that together accounted for 50.92% of the total variance. Orthogonal rotation was chosen rather than oblique rotation in order to produce factors that were as distinct as possible [55].

Factor loadings are reported in table 2. Factor 1 accounted for 36.22% of the variance among all the variables and was correlated with measures that contained a strong cognitive speed component. Measures that loaded most strongly on factor 1 (0.55 or better) [55] included: Letter and Pattern Comparison, Lex Dec RT, SCS RT, Trails A, and Digit Symbol Substitution and Digit Symbol Copy. This factor is interpreted to represent cognitive speed ability. The 2nd factor, which accounted for 8.57% of the variance, included high loadings for measures that encompass a variety of cognitive abilities (HVLT Aver-

Table 1. Descriptive statistics for study variables (n = 530)

	Mean (SD)
Cognitive measures	
Pattern Comparison	27.57 (6.28)
Lex Dec RT	1,416.67 (286.04)
Letter Comparison	40.11 (9.29)
SCS RT	1,394.73 (250.47)
Trails A	43.90 (18.89)
DS substitution-copy	1.22 (0.60)
UFOV	865.70 (289.86)
HVLT avg	7.77 (1.75)
HVLT DI	11.03 (1.21)
MMSE	28.35 (1.71)
WASI Vocabulary	56.69 (8.44)
WASI Matrix Reasoning	53.64 (11.64)
Trails B	137.52 (103.44)
Stroop score	34.73 (21.87)
Digit Span	9.69 (2.11)
Spatial Span	7.41 (1.68)
Sensory measures	
Far visual acuity	71.71 (11.52)
Near visual acuity	0.06 (0.13)
Contrast sensitivity	1.69 (0.15)
Hearing	25.83 (11.66)
Balance	7.10 (1.60)
Measures of function	
TIADL	0.00 (0.60)
RST	1.96 (0.75)
Life-space	7.26 (1.16)
Driving-space	3.43 (1.50)
Driving exposure	5.43 (2.06)

SCS RT = Shape Color Size average reaction time; Lex Dec RT = Lexical decisions average reaction time; DS substitution-copy = Digit Symbol Substitution time corrected by Copy time; UFOV = Useful Field of View; HVLT avg = Hopkins Verbal Learning Test average recall; HVLT DI = Hopkins Verbal Learning Test Discrimination Index; MMSE = Mini Mental Status Exam.

age Recall and Discrimination Index, MMSE, WASI Vocabulary and Matrix Reasoning, Trails B, Stroop), but do not feature a strong processing speed component. Thus, Factor 2 is judged to represent nonspeeded cognitive abilities. The 3rd factor, which accounted for 6.12% of the variance, clearly consists of sensory measures (contrast sensitivity, far and near visual acuity) and is therefore considered to represent sensory ability. Uncorrelated factor scores derived from the factor analysis by the regression method were subsequently used as independent variables in regression analyses. Correlations among cognitive and sensory factors, age and functional measures are presented in table 3.

Table 2. Presentation of factor loadings in rotated component matrix after varimax rotation

Sensory and cognitive variables	Factor 1	Factor 2	Factor 3
Pattern Comparison	0.759	0.301	0.193
Lex Dec RT	0.759	0.067	0.092
Letter Comparison	0.748	0.286	0.189
SCS RT	0.738	0.224	0.115
Trails A	0.578	0.389	0.311
DS substitution-copy	0.558	0.478	0.201
UFOV	0.504	0.377	0.443
HVLT avg	0.141	0.742	0.150
HVLT DI	–0.031	0.653	0.194
MMSE	0.178	0.653	0.164
WASI Vocabulary	0.353	0.609	–0.109
WASI Matrix Reasoning	0.263	0.601	–0.088
Trails B	0.476	0.596	0.196
Stroop score	0.441	0.559	0.212
Digit Span	0.281	0.415	0.022
Spatial Span	0.252	0.380	0.167
Far visual acuity	0.164	0.093	0.762
Near visual acuity	0.036	–0.008	0.750
Contrast sensitivity	0.192	0.061	0.667
Hearing	0.028	0.293	0.448
Balance	0.291	0.070	0.414

SCS RT = Shape Color Size average reaction time; Lex Dec RT = Lexical decisions average reaction time; DS substitution-copy = Digit Symbol Substitution time corrected by Copy time; UFOV = Useful Field of View; HVLT avg = Hopkins Verbal Learning Test average recall; HVLT DI = Hopkins Verbal Learning Test Discrimination Index; MMSE = Mini Mental Status Exam.

Stepwise Multiple Regression

To compare the relative influence of the cognitive speed factor to that of the sensory and nonspeeded cognitive factors on functional performance, stepwise multiple regressions were conducted. The stepwise method was used to empirically determine the best combination of the sensory, cognitive speed and nonspeeded cognitive factors to account for variance in each measure of functional ability. Results are presented in tables 4 and 5.

Overall, stepwise regression analyses revealed that the cognitive speed factor accounted for the most variance in functional performance for RST, driving-space, driving exposure and life-space. However, in every instance nonspeeded cognitive and sensory abilities added to the variance accounted for over and above that of the speed factor alone. One exception was TIADL performance for which the nonspeeded cognitive factor accounted for the most variance. In this instance, both the speed and sensory factor added to the amount of variance explained.

Table 3. Correlations between factor scores of sensory, cognitive speed and nonspeeded cognitive factors, age, and measures of functional ability

	TIADL	RST	Life-space	Driving-space	Driving exposure
Cognitive speed factor	0.383**	0.464**	0.182**	0.241**	0.233**
Nonspeeded cognitive factor	0.417**	0.456**	0.171**	0.169**	0.127**
Sensory factor	0.336**	0.201**	0.097*	0.160**	0.128**
Age	–0.369**	–0.318**	–0.135**	–0.183**	–0.133**

* $p < 0.05$; ** $p < 0.01$; TIADL = Timed Instrumental Activities of Daily Living; RST = Road Sign Test.

Table 4. Summary of stepwise multiple regression analyses for factor scores accounting for objective functional performance

	B	SE B	d.f.	p
TIADL: Variable[a]				
Step 1				
Nonspeeded cognitive factor	0.252	0.024	528	<0.001
Step 2				
Nonspeeded cognitive factor	0.252	0.022	527	<0.001
Cognitive speed factor	0.231	0.022	527	<0.001
Step 3				
Nonspeeded cognitive factor	0.252	0.020	526	<0.001
Cognitive speed factor	0.231	0.020	526	<0.001
Sensory factor	0.203	0.020	526	<0.001
RST: Variable[b]				
Step 1				
Cognitive speed factor	0.464	0.039	528	<0.001
Step 2				
Cognitive speed factor	0.464	0.033	527	<0.001
Nonspeeded cognitive factor	0.456	0.033	527	<0.001
Step 3				
Cognitive speed factor	0.464	0.032	526	<0.001
Nonspeeded cognitive factor	0.456	0.032	526	<0.001
Sensory factor	0.201	0.032	526	<0.001

[a] $R^2 = 0.174$ for step 1 ($p < 0.001$); $\Delta R^2 = 0.147$ for step 2 ($p < 0.001$); $\Delta R^2 = 0.113$ for step 3 ($p < 0.001$).
[b] $R^2 = 0.215$ for step 1 ($p < 0.001$); $\Delta R^2 = 0.208$ for step 2 ($p < 0.001$); $\Delta R^2 = 0.040$ for step 3 ($p < 0.001$).

Speeded and nonspeeded cognitive and sensory abilities accounted for TIADL and RST performance fairly well, explaining 43.4 and 46.3% of the variance, respectively. Although speeded and nonspeeded cognitive and sensory factors accounted for a significant amount of variance in life-space, driving-space and driving exposure, the amount of variance accounted for by these factors was not substantial (7.1, 11.2 and 8.6%).

Table 5. Summary of stepwise multiple regression analyses for factor scores accounting for self-reported functional performance

	B	SE B	d.f.	p
Life-space: Variable[a]				
Step 1				
Cognitive speed factor	0.182	0.043	528	<0.001
Step 2				
Cognitive speed factor	0.182	0.042	527	<0.001
Nonspeeded cognitive factor	0.171	0.042	527	<0.001
Step 3				
Cognitive speed factor	0.182	0.042	526	<0.001
Nonspeeded cognitive factor	0.171	0.042	526	<0.001
Sensory factor	0.097	0.042	526	0.022
Driving-space: Variable[b]				
Step 1				
Cognitive speed factor	0.241	0.042	528	<0.001
Step 2				
Cognitive speed factor	0.241	0.042	527	<0.001
Nonspeeded cognitive factor	0.169	0.042	527	<0.001
Step 3				
Cognitive speed factor	0.241	0.041	526	<0.001
Nonspeeded cognitive factor	0.169	0.041	526	<0.001
Sensory factor	0.160	0.041	526	<0.001
Driving exposure: Variable[c]				
Step 1				
Cognitive speed factor	0.233	0.042	528	<0.001
Step 2				
Cognitive speed factor	0.233	0.042	527	<0.001
Sensory factor	0.128	0.042	527	0.002
Step 3				
Cognitive speed factor	0.233	0.042	526	<0.001
Sensory factor	0.128	0.042	526	0.002
Nonspeeded cognitive factor	0.127	0.042	526	0.002

[a] $R^2 = 0.033$ for step 1 ($p < 0.001$); $\Delta R^2 = 0.029$ for step 2 ($p < 0.001$); $\Delta R^2 = 0.009$ for step 3 ($p = 0.022$).
[b] $R^2 = 0.058$ for step 1 ($p < 0.001$); $\Delta R^2 = 0.028$ for step 2 ($p < 0.001$); $\Delta R^2 = 0.026$ for step 3 ($p < 0.001$).
[c] $R^2 = 0.054$ for step 1 ($p < 0.001$); $\Delta R^2 = 0.016$ for step 2 ($p = 0.002$); $\Delta R^2 = 0.016$ for step 3 ($p = 0.002$).

Hierarchical Multiple Regression

In order to determine how much residual age-related variance in the functional measures remained unexplained after taking the cognitive and sensory factors into account, hierarchical regressions then were conducted for each functional measure. The factors found in the stepwise regressions to significantly account for performance on each measure were entered in Step 1 of each analysis, and age was added in Step 2. The inclusion of age in the 2nd step accounted for a small but statistically significant amount of additional variance in TIADL scores (1.2%) and RST (1.1%). Age accounted for a minimal amount of additional variance in life-space, driving-space and driving exposure that was not significantly greater than the variance accounted for by the cognitive and sensory factors.

Discussion

The results of the factor analysis, while merely exploratory, are interesting. Sensory measures clearly formed their own factor representing underlying sensorimotor abilities. None of these sensory measures loaded significantly on either of the cognitive factors, and only UFOV loaded significantly (accounting for at least 10% of the variance) on the sensory factor. It may be the complexity of UFOV that, while it renders it a less-than-ideal candidate for factor analysis, makes it such a strong predictor of mobility outcomes [8, 16, 33, 56]. These results, combined with results of the regression analyses, indicate that measures which tap both cognitive and sensory abilities may be most strongly associated with functional outcomes.

The stepwise multiple regression analyses revealed that measures of functional ability were best explained by a combination of cognitive factors and sensory status. Even so, it is clear that cognitive abilities, particularly speeded ones, more strongly influence everyday functioning than do sensory abilities, given that sensory abilities are grossly intact. Hierarchical multiple regression analyses revealed that age contributes very little to the prediction of functional ability once an individual's cognitive and sensory status are taken into account, suggesting that successful intervention to improve basic cognitive and sensory abilities could reduce the age-related variance in functional abilities.

More of the variance in TIADL and RST performance could be accounted for by cognitive and sensory factors than was the case with the self-reported mobility measures. This may be due to the less restricted range and more normal distributions of TIADLs and RST than the mobility measures, or these results could indicate that the performance-based TIADL and RST measures more accurately assess the abilities they represent than do the self-report questionnaire items (resulting in greater sensitivity to impairment).

Life-space, driving-space and driving exposure are useful indicators of mobility; however, in this sample there was not much variability in these measures. This could be due in part to the fact that participants had to be mobile enough to come to our offices to participate. More variability might be found in studies that go into the community in order to measure these aspects of mobility in the home as well. Previous studies of life-space and driving-space have found these indices to be significantly related to cognitive speed [6, 15]. Similarly, in this study the cognitive speed factor was the strongest influence on driving-space, driving exposure and life-space. Nevertheless, it is clear that both cognitive and sensory abilities are key to these mobility indices.

A major limitation of this study, and indeed of most of the studies reviewed in this paper, is that it is cross-sectional rather than longitudinal. To truly measure decline in cognitive, sensory and functional abilities with aging, longitudinal studies are needed. It would be interesting to follow a sample to see if these same relationships between cognitive, sensory and functional abilities persist, or how they change longitudinally. Another potential limitation of the study is that the sample was relatively more educated (92% high school graduates) than the US population cohort aged 65 and older (70% high school graduates). Even so, our sample was quite diverse with respect to cognitive and functional abilities, suggesting that any limit on the generalizability of our findings and conclusions is likely to be negligible.

It is important to remember that functional difficulties do not necessarily accompany aging, and that virtually every measure of sensory, cognitive or functional ability in older adults involves a high degree of individual differences. Considering the aging of the population of the United States and many other developed nations, and the number of sensory, cognitive and functional declines known to increase in prevalence with aging, identifying correlates and predictors of functional performance is more important than ever in order to effectively intervene.

It has been suggested by multiple authors that correcting underlying sensory and/or cognitive deficits which occur with aging could improve not only these basic abilities, but also the functional abilities which depend upon them [6, 14, 21]. Many different intervention programs have been developed, but transfer to functional outcomes has not been widespread [35]. Some success has been found with sensory interventions in reducing subsequent automobile accidents [57]. Success has also been found with speed of processing training transferring to improved TIADL and driving performance [58, 59]. Accordingly, the present results highlight the strong relationship of speeded cognitive abilities to functional performance. Overall, however, the implications of these results are that multifaceted training programs targeting both cognitive (speeded and nonspeeded) and sensory abilities may be most effective.

Acknowledgment

This work was partially supported by an NIH Training Grant (5T32AG00274), and the project described was funded by an NIH Merit Award to Karlene Ball (SR37AG05739). The authors thank Gayla Cissell, Western Kentucky University, for her efforts in project coordination and data management, and Patricia Sawyer, University of Alabama at Birmingham, for her helpful comments and suggestions.

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