Extending Neuropsychological Assessments into the Primary Mental Ability Space

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Abstract

The current study projected a neuropsychological battery developed for the detection of dementia into the mental ability factor space. Participants included 499 community-dwelling, non-demented adults, aged 57-95, who completed a neuropsychological battery and primary mental abilities battery. Findings suggested that substantial proportions of variance in most neuropsychological measures can be predicted from the psychometric ability battery. Such information may aid in early identification of individuals at risk for dementia.

A major tradition in the psychological aging community is the psychometric approach to the measurement of cognitive status, cognitive change across age, and the detection of cognitive deficits. However, the specific measurement systems used differ when normal aging is studied versus the detection of neuropathology. The study of normal aging has generally used assessment batteries that are suitable across the entire adult life span, i.e., that cover a wide range of difficulty. By contrast, neuropsychologists typically use measures with relatively low ceilings and floors because they are used to chart deficit from the point in time when it is first noticed until the endpoint of death or total inability to respond to psychological measures. Also, while measures of normal aging cover a wide array of domains to account for individual differences in intellectual competence, neuropsychological measures target specific cognitive deficits.

Because pharmaceutical and/or psychological interventions for the prevention of dementia may soon become available, interest in the early detection of those at risk for cognitive impairment in old age has increased. However, for normally functioning adults, the restricted range of possible scores on neuropsychological tests makes it necessary to explore whether other psychometric measurement systems might be profitably employed for early detection. This would require efforts to project the neuropsychological measurement system into the primary mental ability measurement space in order to develop suitable prediction equations.

The purpose of the current study was to determine the projection of a neuropsychological battery developed for the detection of dementia into the normal mental ability factor space. To determine the variance common to both batteries, it was necessary to identify a sample of normal individuals that included individuals who had begun to experience age-related cognitive decline and who would therefore show sufficient heterogeneity on the neuropsychological measures to

permit cross-battery analyses. Such a sample was available in the latest cycle of the Seattle Longitudinal Study (SLS; Schaie, 1996).

METHOD

Sample

The sample consisted of 499 adults (211 men and 288 women) who were part of the SLS seventh wave data collection in 1997-98 and who ranged in age from 57 to 95 years ($M = 73.07$, $SD = 8.30$) at the time of their neuropsychological assessment. The educational level of this sample ranged from 7 to 20 years ($M = 15.05$, $SD = 2.77$). Participants were included only if they had been tested on the primary mental abilities battery at least one previous occasion (seven years earlier) in addition to the current occasion.

Measures

The Primary Mental Abilities Battery

The original SLS psychometric ability battery was expanded to permit structural analyses with multiple measures marking each of six ability factors. All tests are slightly speeded to be suitable for group administration. The longitudinal markers included in this battery by necessity (i.e., for consistency across successive test administrations) employ the test booklet and answer sheet format (Thurstone & Thurstone, 1949) used since the beginning of the SLS in 1956. However, print size on answer sheets has been enlarged from the original. All other forms use disposable booklets with suitably enlarged type upon which answers are marked directly (cf. Ekstrom, French, Harman, & Derman, 1976; Schaie, 1985). A brief description of the primary abilities and the measures marking them is given below. Descriptive statistics are presented in Table 1 for the 17 primary mental ability measures used in this study.

Inductive Reasoning

This is the ability to identify novel aspects of relationships, and to infer principles or rules from observing the regular occurrence of instances or relationships.

PMA Reasoning (Thurstone & Thurstone, 1949). The subject is shown a series of letters (e.g., a b c b a d e f e) and is asked to identify the next letter in the series.

ADEPT Letter Series (Blieszner, Willis, & Baltes, 1981). This is a parallel form to the PMA Reasoning test.

Word Series (Schaie, 1985). The subject is shown a series of words (e.g., January, March, May) and is asked to identify the next word in the series. Positional patterns used in this test are identical to the PMA Reasoning test.

ETS Number Series (Ekstrom et al., 1976). The subject is shown a series of numbers (e.g., 6, 11, 15, 18, 20) and is asked to identify the next number that would continue the series.

Spatial Orientation

This is the ability to visualize and mentally manipulate spatial configurations, to maintain orientation with respect to spatial objects, and to perceive relationships among objects in space.

*PMA Space (*Thurstone & Thurstone, 1949). The study participant is shown an abstract figure and is asked to identify which six other drawing represents the model in two-dimensional space.

Object Rotation (Schaie, 1985). The subject is shown a line drawing of a meaningful object (e.g., an umbrella) and is asked to identify which of six other drawings represent the model rotated in two-dimensional space.

Alphanumeric Rotation (Willis & Schaie, 1983). The subject is shown a letter or number and is asked to identify which six other drawings represent the model rotated in two-dimensional space.

Test stimuli in the Object and Alphanumeric Rotation tests have the same angle of rotation as the abstract figures in the PMA Space test.

Cube Comparisons (Ekstrom, et al., 1976). In each item, two drawings of a cube are presented; the subject is asked to indicate whether the two drawings are of the same cube, rotated in three-dimensional space.

Numerical Facility

This is the ability to understand numerical relationships and compute simple arithmetic functions.

PMA Number (Thurstone & Thurstone, 1949). The subject checks whether additions of simple sums shown are correct or incorrect.

Addition (Ekstrom, et al., 1976). This is a test of speed and accuracy in adding three single or two-digit numbers.

Subtraction and Multiplication (Ekstrom, et al., 1976). This is a test of speed and accuracy with alternate rows of simple subtraction and multiplication problems.

Verbal Comprehension

Language knowledge and comprehension is measured by assessing the scope of a person's recognition vocabulary.

PMA Verbal Meaning (Thurstone & Thurstone, 1949). A four-choice synonym test which is highly speeded.

ETS Vocabulary II (Ekstrom, et al., 1976). A five-choice synonym test of moderate difficulty level.

ETS Vocabulary IV (Ekstrom, et al., 1976). Another five-choice synonym test consisting mainly of difficult items.

Verbal Memory

This is the ability to encode, store and recall meaningful language units.

Immediate Recall (Zelinski, Gilewski, & Schaie,1993). Subjects study a list of 20 words for 3 1/2 minutes. They are then given an equal period of time to recall the words in any order.

Delayed Recall (Zelinski et al., 1993). Subjects are asked to recall the same list of words as in Immediate Recall after an hour of intervening activities (other psychometric tests).

PMA Word Fluency (Thurstone & Thurstone, 1949). The subject freely recalls as many words as possible according to a lexical rule within a five-minute period.

Neuropsychological Measures

The seventeen neuropsychological measures used in this study are described below. Descriptive statistics for these measures are presented in Table 2.

The CERAD battery

The Consortium to Establish a Registry for Alzheimer's Disease (CERAD) battery was developed to determine presence of cognitive impairment (Morris et al., 1989; Morris, et al., 1993).

The *Mini-Mental State Examination* (MMSE; Folstein, Folstein, & McHugh, 1975; Tombaugh & McIntyre, 1992) is widely used as a screening technique for identifying individuals with possible mental impairment. Although its psychometric characteristics have been questioned, we include this test to link with existing literature and to obtain a better understanding of how this screening instrument projects into the domains commonly measured in the assessment of older normal community dwelling populations.

Verbal Fluency: "Animal Category" (Isaacs & Kennis, 1973). The test measures impairment in verbal production, semantic memory and, language.

Modified Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1984; Van Gorp, Satz, Kiersch, & Henry, 1986) involves the verbal identification of two dimensional objects within 20 seconds. If the name is not produced in that time, a semantic cue is given, and after another 20 seconds a phonemic cue is provided with cuing if the subject has difficulty. It is used clinically to measure impairment of language functions. The abbreviated version of this test is suitable for our population and requires no more than twenty minutes.

Word List Memory (Atkinson & Shiffrin, 1971). A free recall task of newly learned information involving a 10 word list with multi trials.

Constructional Praxis (Rosen, Mohs, & Davis, 1984). The test involves four line drawings in increasing complexity. Although both immediate and delayed recall are measured, only the delayed score was used in this analysis.

Subtests from the Wechsler Adult Intelligence Scale (WAIS R)

A short form of the WAIS-R (Wechsler, 1981) is given. The short form consists of the most commonly used tests from both Verbal and Performance scales, tests that show early as well as late decline in old age.

Vocabulary test. This vocabulary test is the most commonly used measure of maintained verbal functions in clinical practice and clinically oriented research.

Comprehension test. A measure of common knowledge, may reflect intactness of logical thought.

Digit symbol substitution test. A speeded measure involving the matching of symbols and numbers.

Block design test. This is the classical clinical test of spatial visualization and has sometimes been used by neuropsychologists to identify problems in the visuo-motor pathways.

Digit Span test. A measure of short-term memory requiring the recall of forward and backward number series.

Other neuropsychological measures

The Wechsler Memory Scale (WMS-REVISED; Ryan, Paolo, & Brugardt, 1990, 1992; Wechsler, 1981) is one of the oldest clinical instruments for assessing memory impairment.

However, we only use Logical memory, with immediate and delayed recall because other parts of the WMS overlap with the other measures in our battery:

The Trail-Making Test is one of the earliest measures used by neuropsychologists to detect difficulty in attention and cognitive inflexibility (Reitan & Wolfson, 1985). Part A requires tracing a path among a set of numbers. Part B involves tracing a path that requires shifting between numbers and letters.

The Fuld Object Memory Test (Fuld, 1977) is a free recall measure of objects. It includes sub-scales for storage, retrieval and ineffective memory. The retrieval and rapid verbal retrieval scores were used in the extension analysis.

The Mattis Dementia Rating Scale (MDRS; Mattis, 1989) is a sensitive index of cognitive functioning in AD patients. It yields a total score and five subscale scores (attention, initiation and perseveration, construction, conceptualization, and memory). The total score was used in the extension analysis. It provides good discrimination between normal and cognitively impaired groups (Vitaliano, Russo, Breen, Vitello, & Prinz, 1986). The MDRS has also been found be sensitive to change as dementia progresses (Kiyak, Teri, & Borson, 1994).

Assessment Procedure

The primary mental ability measures described above were administered to small groups of subjects as part of a broader five-hour battery spread over two sessions, each with breaks. The tests were administered by an examiner who was assisted by a proctor. Testing locations were at familiar sites close to the homes of our participants. The neuropsychology battery was administered individually in the participants' homes during a 2 1/2 hour session with a 15-minute break.

Statistical Procedures

Analysis details

All models were estimated using the full information maximum likelihood procedure implemented in Amos 4.0 (Arbuckle & Wothke, 1999). This procedure estimates the model parameters from the raw data matrix, rather than from a covariance (or correlation) matrix and allows individuals to have missing data. All variables were analyzed in T-score metric ($M = 50$, $SD = 10$). Five neuropsychological variables with skewness greater than 2.00 were normalized using a McCall transformation (Garrett, 1966) before transforming to T-score metric. These variables were Fuld Retrieval, Mattis grand total, the Boston Naming Test, the MMSE, and

Trails A. Also before T-score transformation, values above 300 seconds on Trails B were trimmed to a value of 300, and values below 102 on the Mattis total score were trimmed to 102.

Primary mental abilities factor structure

The factor structure into which the neuropsychological battery was to be projected was based on an earlier analysis using a larger sample from the SLS (Schaie, Dutta, & Willis, 1991). Due to the speeded nature of all tests included, it was determined that it was necessary to remove the Perceptual Speed factor and related tests from the extension analysis. The fit of the factor structure for the five mental ability factors remaining (Inductive Reasoning, Spatial Orientation, Numeric Ability, Verbal Comprehension, and Verbal Memory) was then assessed in the present sample. Factor variances were constrained to unity, and factor inter-correlations, factor loadings, and unique variances were estimated freely. The fit for this model was good: χ^2 (108, N = 499) = 536.08, $p < .001$; *CFI* = .99, *RMSEA* = .09. The standardized factor loadings, shown in Table 3, were significant for all salient loadings ($p < .001$) and were fairly comparable to the values for the structure reported by Schaie et al. (1991). The factor intercorrelations in this sample, shown in Table 3, were also similar to the values reported by Schaie et al. (1991).

Extension analysis

In order to project the neuropsychological battery into the primary mental abilities space, the cognitive data matrix was augmented by as many columns as there were neuropsychological measures (i.e., 17). In the extension analysis (Dwyer, 1937; Tucker, 1971), factor loadings, factor intercorrelations, and intercepts for the cognitive variables were constrained to the unstandardized values from the confirmatory factor analysis solution that was obtained for this sample. Factor variances were again set to unity. Factor loadings for the neuropsychological measures on each of the primary mental ability factors were then freely estimated, providing information on the projection of these measures into the previously established five-factor primary mental ability factor structure. Correlated residuals were estimated between subtests of the same measure (i.e., between WMS-R Immediate and Delayed, between Trails A and B, and between Fuld Retrieval and Fuld Rapid Verbal Retrieval).

RESULTS AND CONCLUSIONS

The current study used the method of extension analysis to project the neuropsychological measures into a five-factor primary mental ability factor structure. The

relationship of the neuropsychological measures to the mental ability factors was assessed via significant factor loadings of the neuropsychological tests on the five mental ability factors. These factor loadings are shown in Table 4. As might be expected, the neuropsychological assessment measures, when extended into the psychometric abilities factor structure, generally spread over two or more of the psychometric abilities. All measures, except for the WAIS-R Digit Span, Vocabulary, Comprehension and Block Design scales, had significant loadings on the Verbal Memory factor. Of the latter scales, Digit Span, Vocabulary and Comprehension had their largest extensions into the Verbal Comprehension factor, while Block Design extended most prominently into the Spatial Orientation factor.

However, examination of the primary (i.e., largest) loading for each test revealed a somewhat more simple explanation of the factors. Six tests had their highest loading on the Verbal Memory factor, and five of these are primarily identified as memory tests: Word List Recall, WMS-R Immediate and Delayed Recall, Fuld Retrieval and Rapid Verbal Retrieval. The sixth test, the MMSE, also has a strong verbal memory component. A different set of six tests loaded most strongly on the Spatial Orientation factor, and five of these six have a significant spatial ability component: Constructional Praxis Delayed, WAIS-R Digit Symbol and Block Design, and Trails A and B. The sixth test on this factor, the Boston Naming Test, while often found to load on spatial orientation, is primarily a verbal ability measure. Six tests had their highest loading on the Verbal Comprehension factor, although the loading for the WAIS-R Immediate Recall on this factor was equal to that for the Verbal Memory factor. Three of these tests were primarily verbal ability tests: Verbal Fluency, WAIS-R Vocabulary and WAIS-R Comprehension. Although the WAIS-R Digit Span and WMS-R Immediate had high loadings on the Verbal Comprehension factor, they also had equal or nearly equal loadings on other factors --

- the Inductive Reasoning and Verbal Memory, respectively. These double loadings may indicate the multiple abilities involved to complete these tasks. No test had its largest loading on the Inductive Reasoning or the Numeric Ability factor.

Most measures had a secondary loading on the Spatial Orientation factor, except for the MMSE, the WAIS-R Digit Span scale, and the Wechsler Memory Immediate Recall. Several measures also had secondary and/or tertiary loadings on the Inductive Reasoning and Numeric Ability factors. The negative loadings found for Trails were expected because, for that measure, a large score (time to completion) was unfavorable. However, the other small but significant negative loadings, particularly on the Inductive Reasoning factor, seem counter-intuitive, but given their magnitude, may not be replicable.

These findings suggest that, at least for the main components of the neuropsychological battery, we may be able to predict substantial proportions of variance from our psychometric ability battery.

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Table 1. *Descriptive Statistics for Primary Mental Ability Measures*

Measure	*N*	*M*	*SD*	*Range*
PMA Reasoning	497	50.46	8.22	32-71
ADEPT Letter Series	497	46.56	8.68	25-69
Word Series	497	45.75	9.60	20-68
Number Series	490	47.50	9.33	30-78
PMA Space	499	49.50	9.12	27-79
Object Rotation	498	47.51	9.60	14-64
Alphanumeric Rotation	497	45.63	10.60	14-62
Cube Comparison	494	46.39	8.28	28-74
PMA Verbal Meaning	499	51.71	9.12	22-63
ETS Vocabulary II	498	51.79	9.70	2-65
ETS Vocabulary IV	497	51.86	9.51	17-67
PMA Number	498	48.93	9.09	28-83
Addition	497	48.03	10.50	20-84
Subtraction and Multiplication	497	46.44	9.95	21-72
PMA Word Fluency	499	47.83	9.93	21-82
Immediate Recall	497	46.03	10.16	18-65
Delayed Recall	496	46.58	9.96	25-66

Note. All variables were rescaled to T-score metric.

Table 2. *Descriptive Statistics for Neuropsychological Measures*

Measure	*N*	*M*	*SD*	*Range*
MMSE [a]	499	49.58	9.01	19-60
Verbal Fluency	499	49.94	10.02	19-85
Boston Naming Test [a]	499	49.10	8.16	19-56
Word List Recall	497	50.07	10.19	17-63
Constructional Praxis Delayed	497	49.99	9.88	22-62
WAIS-R Vocabulary	498	50.22	9.71	4-66
WAIS-R Comprehension	498	50.11	9.85	16-70
WAIS-R Digit Symbol	497	49.97	9.99	15-77
WAIS-R Block Design	498	50.06	9.99	22-74
WAIS-R Digit Span	499	50.03	10.03	22-79
WMS-R Immediate	498	49.99	10.03	17-71
WMS-R Delayed	498	50.01	10.00	27-72
Trails A [a]	497	49.99	10.02	19-81
Trails B [b]	494	49.98	9.97	33-83
Fuld Retrieval [a]	496	49.81	9.79	21-73
Fuld Rapid Verbal Retrieval	496	50.01	10.01	14-86
Mattis Total [a, b]	499	50.06	9.84	21-69

Note. All variables were rescaled to T-score metric.

[a] Neuropsychological variables with skew > 2.00 were normalized with a McCall transformation before rescaling to T-score metric. [b] Values above 300 on Trails B were trimmed to a value of 300, and values below 102 on the Mattis Total were trimmed to a value of 102.

Table 3. *Standardized loadings for cognitive ability factors (N = 499).*

Measure	Primary Mental Ability Domain				
	Inductive Reasoning	Spatial Orientation	Verbal Comprehension	Numeric Ability	Verbal Memory
PMA Reasoning	.91				
ADEPT Letter Series	.86				
Word Series	.88				
Number Series	.72				
PMA Space		.87			
Object Rotation		.87			
Alphanumeric Rotation		.79			
Cube Comparison		.65			
PMA Verbal Meaning			.66		
ETS Vocabulary			.85		
Advanced Vocabulary			.90		
PMA Number				.87	
Addition				.94	
Subtraction and Multiplication				.86	
Word Fluency			.39		.29
Immediate Recall					.97
Delayed Recall					.93
Factor	Intercorrelations				
1. Inductive Reasoning	---				
2. Spatial Orientation	.72	---			
3. Verbal Ability	.56	.36	---		
4. Numeric Ability	.57	.44	.37	---	
5. Verbal Memory	.57	.34	.47	.34	---

Note. Fit statistics for this model were: χ^2 (df = 108, N = 499) = 536.08, p < .001; CFI = .99, $RMSEA$ = .09.

Table 4. *Factor loadings of neuropsychological measures on primary mental ability factors.*

Neuropsychological Measure	Inductive Reasoning	Spatial Orientation	Verbal Comp.	Numeric Ability	Verbal Memory	Unique Variance
MMSE [a]	.13	.00	.19***	.15**	.30***	.64
Verbal Fluency	-.10	.24***	.41***	-.07	.24***	.65
Boston Naming Test [a]	-.11	.41***	.29***	-.16**	.11*	.75
Word List Recall	-.20**	.20***	.07	-.06	.71***	.52
Const. Praxis Delayed	-.03	.42***	.10*	-.09	.31***	.65
WAIS-R Vocabulary	-.16**	.13**	.93***	-.08*	.04	.21
WAIS-R Comprehension	-.22**	.22***	.74***	-.11*	.08	.48
WAIS-R Digit Symbol	.19**	.37***	-.11**	.25***	.23***	.41
WAIS-R Block Design	.17*	.50***	.13**	-.02	.06	.47
WAIS-R Digit Span	.30***	-.10	.31***	.11*	-.05	.74
WMS-R Immediate	.13	.11	.33***	-.19***	.33***	.59
WMS-R Delayed	.02	.17**	.26***	-.15**	.47***	.55
Trails A [a]	-.10	-.41***	.07	-.07	-.18***	.65
Trails B [b]	-.23**	-.34***	.02	-.15***	-.17***	.46
Fuld Retrieval [a]	-.05	.28***	-.01	-.02	.58***	.55
Fuld Rapid Verbal Retrieval	.00	.16**	.25***	.09*	.37***	.56
Mattis Total [a, b]	-.04	.21***	.34***	.03	.29***	.59

* $p < .05$; ** $p < .01$; *** $p < .001$.

[a] Neuropsychological variables with skew > 2.00 were normalized with a McCall transformation before rescaling to T-score metric. [b] Values above 300 on Trails B were trimmed to a value of 300, and values below 102 on the Mattis Total were trimmed to a value of 102.