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Factor Analysis of Four Measures of Prefrontal Lobe Functioning

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The Wisconsin Card Sorting Test, Stroop Test, Verbal Fluency (FAS), and Auditory Consonant Trigrams are commonly used measures of prefrontal lobe dysfunction. However, insufficient data are available regarding the specific functions assessed by these tests and the relationship of the tests to each other. These four tests, as well as measures of IQ, memory, attention, and processing speed, were administered to 250 subjects (138 patients and 112 controls). Factor analysis yielded three factors, and a higher order frontal lobe factor, using a dimensional factor analytic methodology. Present findings revealed modest correlations among the prefrontal tests, suggesting that the tests tap somewhat different abilities and are not redundant. Adequate assessment of prefrontal lobe abilities appears to require use of more than one test. © 1998 National Academy of Neuropsychology. Published by Elsevier Science Ltd

Identification of cognitive tests sensitive to prefrontal lobe dysfunction has been an emerging interest within the field of neuropsychology. Several tests, such as the Wisconsin Card Sorting Test, Stroop Test, Verbal Fluency (FAS), and Auditory Consonant Trigrams, have been validated as ''frontal lobe'' tests based on documentation of poorer performance on these measures by prefrontal lobe-lesioned patients as compared to patients with nonfrontal damage

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(Benton, 1968; Goodglass & Kaplan, 1979; Milner, 1963, 1964; Perret, 1974; Robinson, Heaton, Lehman, & Stilson, 1980; Stuss et al., 1982).

These tests are now commonly used as measures of prefrontal lobe dysfunction in research and clinical practice, although insufficient data are available regarding the specific functions assessed by each of these tests. In addition, minimal information is available regarding the relationship of the tests to each other. It would be logical to assume that scores on the prefrontal lobe tests are moderately to highly correlated, given that they purport to measure functions subserved by the same brain area. However, no empirical evidence has emerged to support this hypothesis, and, in fact, some data have emerged to suggest that the tests may not be significantly correlated. For example, Goldberg and colleagues (1988) failed to detect a significant relationship between the Wisconsin Card Sorting Test and verbal fluency in a small sample of schizophrenic patients.

On a practical level, it is not clear how many frontal lobe tests should be included in a battery to fully assess prefrontal abilities or which tests, if any, are redundant.

Factor analytic methods have been used to examine traditional neuropsychological batteries, which have included a single prefrontal lobe test (i.e., Wisconsin Card Sorting Test). However, the literature has been contradictory, with some studies demonstrating that the Wisconsin Card Sorting Test loads on a single factor by itself (Swiercinsky & Hallenbeck, 1975), is represented on multiple factors along with nonfrontal test scores (Wagman, Heinrichs, & Carpenter, 1987), or does not have high loadings on any factors extracted (Bornstein, 1983). Factor analytic methods have rarely been applied to a cognitive battery containing several prefrontal lobe tests, although the available literature is promising. Specifically, preliminary evidence suggests that various prefrontal lobe tests may load on a single factor (Goldberg et al., 1988), however, this remains to be replicated on a large sample.

The purpose of the present study was to define a stable set of factors within a large heterogeneous (combined patient and control) population that describe the relationship among the scores obtained on several prefrontal lobe tests: the Wisconsin Card Sorting Test, Stroop Test, Verbal Fluency (FAS), and Auditory Consonant Trigrams. An additional goal was to ascertain if the frontal lobe tests load with nonfrontal tests within a neuropsychological battery.

METHOD

Subjects

The total sample consisted of 250 subjects (138 outpatients and inpatients referred for neuropsychological testing at Harbor-UCLA Medical Center, and 112 controls). Patient diagnoses included dementia, head trauma, cerebral vascular accident, alcohol or drug abuse, brain tumor, seizure disorder, late onset psychosis, attention deficit disorder, toxic encephalopathy, obsessive compulsive disorder, and multiple sclerosis (see Table 1).

Most of the patients with psychiatric diagnoses were subjects in research protocols and diagnoses from the *Diagnostic and Statistical Manual of Mental Disorders*, third edition, revised (*DSM-III-R*; American Psychiatric Association, 1987) were determined by a psychiatrist or psychiatric nurse using structured clinical interviews. The remaining psychiatric diagnoses were based on clinical interview by a psychiatrist or psychologist. Neurologic diagnoses were made by neurologists or psychiatrists based on clinical exam and MRI brain imaging findings.

Control subjects were recruited through newspaper ads, relatives and friends of patients, and personal contacts. Exclusion criteria included history of psychotic or major affective disorder, current or past history of alcohol or other substance abuse, significant head injury (loss of consciousness greater than 15 minutes), neurological illness, or significant medical

TABLE 1
Patient Diagnoses

Diagnosis	Number of Subjects
Major depression	20
Agenesis of the corpus callosum	1
Stroke	8
Cysticercosis	1
Multi-infarct dementia	8
Late-life psychosis	25
Obsessive compulsive disorder	39
Learning disability/attention deficit disorder	4
Alcohol abuse	4
Brain tumor	2
Head injury	6
Toxic encephalopathy	4
Autism	1
Anoxia	1
Schizophrenia	7
Multiple sclerosis	1
Alzheimer's disease	5
Frontotemporal dementia	1

illness that could affect central nervous system function (e.g., uncontrolled hypertension, diabetes, etc.).

Mean age, years of education, and Wechsler Adult Intelligence Scale-Revised (WAIS-R) Verbal IQ (VIQ) and Performance IQ (PIQ), and sex ratio for the whole sample, and patients and controls separately are contained in Table 2.

Procedures

Subjects were administered a 2-hour battery of tests in the following order: an abbreviated version (Satz-Mogel) of the WAIS-R (Adams, Smigielski, & Jenkins, 1984), copy of the Rey-Osterrieth Complex Figure, Verbal Fluency (FAS), 3-minute delayed recall of the Rey-Osterrieth Complex Figure (Boone et al., 1993), immediate recall of the Logical Memory and Visual Reproduction subtests of the Wechsler Memory Scale (Wechsler, 1945), the Wisconsin Card Sorting Test (WCST), the Stroop Test (Comalli, Wapner, & Werner, 1962 version), Auditory Consonant Trigrams (ACT, using 3,″ 9,″ and 18″ delays; Boone, Miller,

TABLE 2
Mean Age, Years of Education, Verbal IQ (VIQ) and Performance IQ (PIQ), and Sex Ratio for the Whole Sample, and for Patients and Controls Separately

	Total	Patients	Controls
	M (*SD*)	*M* (*SD*)	*M* (*SD*)
Age*	55.50 (15.52)	51.15 (16.25)	60.87 (12.74)
Education**	13.92 (2.75)	13.50 (2.88)	14.50 (2.56)
VIQ	107.65 (16.27)	102.86 (16.58)	113.55 (13.82)
PIQ	104.36 (15.43)	98.47 (14.91)	111.61 (13.90)
Sex (m/f)**	135/115	67/71	68/44

*$T = 5.17$, $p < .0001$. **$T = 2.87$, $p < .005$. ***$\chi^2 = 3.68$, $p > .05$.

Lesser, Hill, & D'Elia, 1990), and 45-minute delayed recall for the Logical Memory and Visual Reproduction subtests of the Wechsler Memory Scale (Rausch & Babb, 1993).

The Wechsler Memory Scale subtests, Rey-Osterrieth Complex Figure, and WAIS-R were included as marker variables to anchor factors representing nonfrontal functions of verbal (Logical Memory) and nonverbal visual memory (Visual Reproduction and Rey-Osterrieth), intellectual level (WAIS-R VIQ and PIQ), attention (Digit Span), and information processing speed (Digit Symbol).

The WCST was scored according to criteria suggested by Heaton (1981). The following WCST test scores were used for data analysis: number of categories, errors, perseverative responses, and percent conceptual level responses. The scores utilized from the Stroop Test were time in seconds to complete part A, part B, and part C. The scores employed from the ACT measure included total score out of 60, and number of perseverations and altered sequences. A perseveration was defined as the reporting of an incorrect letter that was used as an answer on the preceding trial; a total of 57 perseverations was possible. Altered sequence referred to reporting of correct letters but in the wrong positions within the trigram; a total of 20 altered sequences was possible. The FAS score was total words generated across the three trials.

The Logical Memory subtest was scored according to Schear's (1985) criteria, and the Visual Reproduction subtest was scored according to the Wechsler Memory Scale manual (Wechsler, 1945) and Trahan's (1987) guidelines. The scores used for analysis were percent retention over 45-minute delayed recall for the two subtests. Rey-Osterrieth figures were scored according to Taylor's criteria (in Lezak, 1995); percent retention over 3-minute delayed recall was used for analysis. Verbal IQ and Performance IQ were used in place of Full Scale IQ in the statistical analyses so that the relationship between the frontal lobe tests and verbal versus perceptual intelligence could be explored differentially. Scaled scores for the Digit Span and Digit Symbol subtests were also used for analysis.

Statistical Analyses

A dimensional factor analysis approach was employed. The extraction method was principal axes with two iterations for communalities. In the dimensional analysis, the principal factors were extracted from the correlation matrix using communality estimates. Factors deemed nonsignificant by Barlett's test were dropped and the number of factors were then reduced further by the use of Verlicer's minimum average partial (MAP) correlational method. The rotation procedures used were Varimax and then Promax (Gorsuch, 1983).

Dimensional analyses were used to separate the overlapping variances among the independent or dependent variables so that they could be tested directly. This was accomplished by establishing a common factor for the variance that several variables have in common. UNIMULT Statistical analysis program was used to compute the factors (Gorsuch, 1991).

RESULTS

Table 3 presents the correlations between factors.

To provide a lower bound for the communality in our sample, squared multiple correlations for each variable were used. However, since R^2 can be spuriously high due to capitalization upon chance, a corrected (shrunken) R^2 was also used to obtain the best lower bound for the population communality itself.

TABLE 3
Correlation Matrix

	PIQ	LM	VR	FAS	R-O	SA	SB	SC	ACTT	ACTP	ACTS	WC	WP	WE	WCR	Dsp	Dsy
VIQ	.59	.23	.24	.54	.32	−.43	−.36	−.35	.47	−.28	−.25	.39	−.45	−.46	.45	.58	.49
PIQ		.21	.20	.33	.40	−.32	−.32	−.31	.34	−.14	−.01	.26	−.34	−.35	.34	.33	.66
LM			.19	.12	.05	−.16	−.17	−.18	.18	−.01	−.06	.22	−.25	−.24	.24	.18	.12
VR				.13	.30	−.08	−.15	−.23	21	−.10	−.12	.33	−.31	−.37	.36	.16	.04
FAS					.08	−.54	−.48	−.43	.40	−.18	−.22	.32	−.35	−.37	.37	.47	.33
R-O						−.26	−.28	−.31	.09	−.02	−.03	.22	−.27	−.32	.31	.08	.28
SA							.75	.67	−.30	.08	.18	−.29	.34	.30	−.30	−.28	−.47
SB								.71	−.34	.14	.18	−.34	.40	.37	−.38	−.24	−.42
SC									−.28	.14	.16	−.36	.37	.36	−.37	−.18	−.41
ACTT										−.52	−.26	.31	−.38	−.37	.37	.43	.28
ACTP											.37	−.16	.17	.18	−.17	−.33	−.10
ACTS												−.01	.01	.03	−.03	−.29	−.01
WC													−.79	−.91	.92	.15	.24
WP														.85	−.84	−.19	−.31
WE															−.99	−.20	−.30
WCR																.20	.29
Dsp																	.27

Note. VIQ = Verbal IQ; PIQ = Performance IQ; LM = Logical Memory; VR = Visual Reproduction; FAS = Verbal Fluency; R-O is Rey-Osterrieth Complex Figure; SA = Stroop Test (ST) A; SB = ST B; SC = ST C; ACTT = Auditory Consonant Trigrams (ACT) Total; ACTP = ACT Perseveration; ACTS = ACT Sequence; WC = Wisconsin Card Sorting Test (WCST) Categories; WP = WCST Perseveration; WE = WCST Errors; WCR = WCST Conceptual Level Responses; Dsp = Digit Span; and Dsy = Digit Symbol.

For the varimax sloution, using a .40 loading criteria based on the MAP (Verlicer, 1977) and a correlation method three factors were identified: WCST scores (categories, percent conceptual level responses, errors, perseverative responses) loaded robustly on the first factor; FAS, Stroop A, Stroop B, Stroop C scores and Digit Symbol were represented on the second factor; and VIQ, PIQ, ACT total, ACT perseveration, ACT sequence scores, Digit Span, Digit Symbol, and Rey-Osterrieth percent retention loaded on the third factor (see Table 4).

Wechsler Memory Scales scores did not load on any factor. Factor one accounted for 23% of variance, while factors two and three accounted for 16 and 13% of the variance, respectively.

While the factor structure remained fairly similar, overlap between the factors with the Promax rotation was noted. Thus, factor 1 correlated −.54 with factor 2, and .54 with factor 3, while the correlation between factors 2 and 3 was −.62. Since these correlations fell in the moderate range according to Cohen criteria (Cohen, 1988), the three factors were analyzed further. That yielded a 1-factor solution, confirming the notion that these tests do measure a higher order ‘‘frontal lobe factor’’ (see Table 5).

A final analysis was performed to test for mean differences in the factors among the normal controls and the patients using extension analysis (Gorsuch, 1991). Multivariate hierarchical analysis of variance was used to determine differences between groups. Results indicated that normal controls and patients were significantly different on factor 1 only ($p < .0001$) (see Table 6).

DISCUSSION

Dimensional factor analysis of 18 test variables that included four prefrontal tests in a sample of 250 subjects resulted in extraction of three factors, each of which contained high loadings from ‘‘frontal lobe’’ tests. The three factors loaded onto a higher order ‘‘frontal lobe factor,’’ suggesting that these tests tap frontal lobe functioning, albeit differently.

The first factor, labeled ‘‘cognitive flexibility,’’ incorporated all the WCST variables entered in the analyses (categories, percent conceptual level responses, errors, perseverative responses). Factor 2, ‘‘speeded processing,’’ was represented by the Stroop, Verbal Fluency (FAS), and Digit Symbol. Factor 3, reflecting test performance mostly affected by ‘‘basic/divided attention and short-term memory,’’ contained high loadings on Auditory Consonant Trigrams, Digit Span, Digit Symbol, and Rey-Osterrieth percent retention. It should be noted that VIQ and PIQ scores particularly loaded on this factor, indicating that intellectual ability is very important to the performance of these tests, and that, as expected, these global scores correlate highly with their own subtests. Wechsler Memory Scale scores (Logical Memory, Visual Reproduction) did not load on any factor, suggesting that these tasks tap a different construct than that measured by prefrontal tests.

The observation that WCST scores loaded on the first factor only suggests that measurement of cognitive flexibility as reflected in ability to shift set, efficient problem-solving, and ability to modify behavior in response to external feedback, is unique to the WCST. These specific skills do not appear to be assessed by the other prefrontal tests.

The finding that Stroop and Verbal Fluency loaded together on a separate, second factor with Digit Symbol was somewhat unexpected. Stroop C traditionally has been considered a measure of cognitive inhibition (Boone et al., 1990), while Verbal Fluency has been viewed as a measure of spontaneity/sustained mental productivity (Daigneault, Braun, & Whitaker, 1992). However, our data suggest that these two measures appear to be particularly sensitive

TABLE 4
Varimax Factor Structure (Factor-Variable Correlations)

Variable	Factor 1	Factor 2	Factor 3	Communalities: Shrunken r^2	Communalities: Final	Promax Solution	1st Unrotated Factor
VIQ	.34	−.33	**.60**	.56	.59	.50	.59
PIQ	.29	−.38	**.41**	.53	.40	.44	.57
Logical Memory Percent Retention	.28	−.20	.13	.12	.13	.34	.18
Visual Reproduction Percent Retention	.32	−.14	.21	.23	.17	.37	.29
Rey-Osterrieth	.25	−.16	**.40**	.23	.24	.34	.29
FAS	.22	**−.44**	.36	.38	.37	.37	.43
Stroop A	−.16	**.82**	−.15	.65	.72	−.37	.67
Stroop B	−.23	**.84**	−.13	.71	.78	−.44	.73
Stroop C	−.24	**.74**	−.13	.60	.62	−.43	.63
ACT Total	.28	−.27	**.54**	.42	.44	.42	.46
ACT Perseveration	−.10	.01	**−.54**	.31	.31	−.19	.36
ACT Sequences	.00	.04	**−.41**	.17	.17	−.07	.23
WCST Categories	**.90**	−.20	.08	.86	.85	.92	.87
WCST Perseveration	**−.82**	.21	−.16	.73	.74	−.86	.75
WCST Errors	**−.96**	.19	−.15	.98	.98	−.99	.98
WCST Concept.	**.96**	−.21	.14	.98	.97	.99	.98
Digit Span	.07	−.17	**.63**	.39	.44	.21	.43
Digit Symbol	.16	**−.43**	**.41**	.50	.38	.33	.53
Percent of Variance	**23**	**16**	**13**				

Note. Proportion of loadings in hyperplane = .06. VIQ = Verbal iQ; PIQ = Performance IQ; ACT = Auditory Consonant Trigrams; WCST = Wisconsin Card Sorting Test.

TABLE 5
Factor Structure

Variable	1
Factor 1	.63
Factor 2	.68
Factor 3	.49
Percent of variance	36

to speeded mental processing as manifested by the fact that they shared more variance in common with Digit Symbol than they did with other prefrontal and nonfrontal tests. As a consequence of this relationship, it is possible that poor performance on Stroop and FAS could result from an impairment in speed of information processing separate from any frontal deficits in generation or inhibition.

Similarly, Auditory Consonant Trigrams, a prefrontal measure of divided attention (Stuss et al., 1985), loaded on a third factor with tests of basic attention (Digit Span), processing speed (Digit Symbol), and short-term memory (Rey-Osterrieth percent retention), suggesting that impairments in any of these collateral nonfrontal skills could lead to lowered performance on Auditory Consonant Trigrams separate from any deficits in divided attention per se. This finding actually is not particularly unexpected given that Auditory Consonant Trigrams has been used both as a measure of short-term memory (Lezak, 1995, pp. 432–433) as well as divided attention.

Despite the fact that a higher order frontal lobe factor emerged, consolidating the three factor structure model for the tests we used, correlations among the different tests of frontal lobe functioning were relatively low (i.e., the correlations reflected no more than 30% shared variance between tests). This may be a function of shared variance with various nonfrontal functions (e.g., mental speed, attention, memory) as discussed above, unreliability of the tests rather than differences in abilities sampled (i.e., error of measurement; Bond & Buchtel, 1984), and/or differences in test difficulty (Bond & Buchtel, 1984).

In addition, some of the frontal tests have been identified as associated with function of a particular hemisphere, although the research has been contradictory (see review by Stuss & Benson, 1986). If some of the tests are associated with left frontal lobe functioning and others tied to right frontal lobe functioning, low correlations could be expected to emerge. Even within a hemisphere, discrete networks of prefrontal function may exist. For example, recent theoretical models have suggested that there may be as many as five parallel but segregated frontal-subcortical circuits within each hemisphere, each with its own behavioral (and perhaps

TABLE 6
Multivariate Hierarchical Analysis of Variance for Group Differences on Three Factor Solution

Variable	Effect Size	Pillai-Bartlett V	*df* 1	*F*-Ratio	*p*
Factor 1	.33	.11	1	30.26	$<.0001$
Factor 2	.01	.00	1	.03	ns
Factor 3	.08	.01	1	2.50	.11
Averaged *R*	.20	.12	3	10.79	$<.0001$

Note. *df* 2 = 245. ns = nonsignificant.

cognitive) manifestations (Cummings, 1993). To the extent that the different prefrontal tests are related to separate anatomic circuits, intertest correlations will be limited.

Of note, the current factor solution was different in the patient and normal control population only in the area of cognitive flexibility (factor 1). The normal controls scored higher (i.e., performed better) on the measures subsumed under the cognitive flexibility factor. Speed of processing (factor 2) and basic/divided attention and short-term memory (factor 3) behaved consistently in the two populations. This difference on factor 1 reflects the fact that patient scores on WCST had very wide variability. The patients were slightly younger than controls but this is not likely to have impacted WCST performance given that age has generally not been found to affect WCST scores (Boone et al., 1990) and, if anything, the younger age of patients should have enhanced, not worsened performance.

The tests in the battery were typically administered in a standardized order, and it is unknown whether subtle test order effects may have influenced the results of this study, although the available literature generally suggests that order effects are minimal (Neuger et al., 1981).

Findings from this study have direct applications for clinical practice. First of all, no single prefrontal test can serve as ‘‘the measure’’ of prefrontal abilities. The various measures provide unique information regarding executive skills. Thus, in clinical practice, at least three frontal tests, drawn from each of the three factors, should be administered to fully assess executive functions, and it is reasonable to expect discrepancies between and among these tests as a direct result of the circumscribed cognitive areas they each measure.

Secondly, Stroop C and Verbal Fluency scores need to be interpreted within the context of mental speed, while Auditory Consonant Trigrams performance should be considered in conjunction with attention/memory scores. For example, if deficits in information processing speed are prominent on such speeded tasks as Digit Symbol or Stroop A and B, administration of Stroop C and Verbal Fluency are unlikely to provide information regarding prefrontal functions of inhibition and generation; low scores will simply be an artifact of slowed processing. In this case, it would be particularly important to administer nontimed prefrontal tests, such as Wisconsin Card Sorting Test and Auditory Consonant Trigrams. Similarly, if attentional and/or memory impairments are prominent, little additional information regarding prefrontal functions will be gained by administering Auditory Consonant Trigrams; low scores on this test will simply reflect impaired basic attention and/or memory.

Stuss and Benson (1986) note that assessment of prefrontal abilities is problematic due to the overarching/organizational nature of these skills; test responses are by necessity filtered through such nonfrontal skills as attention, mental speed, language, visual spatial ability, motor speed, etc. These authors lament that ‘‘clear demonstration of frontal executive control has been difficult to achieve’’ (p. 147). However, the fact that the Wisconsin Card sorting Test was represented by itself on a unique factor suggests that this test may be tapping a relatively ‘‘pure’’ frontal behavior. It may be possible to modify the administration and/or scoring formats for the other prefrontal tests to make the scores less dependent on nonfrontal skills. For example, calculation of errors, or ratio of time used to complete Part C of the Stroop relative to Parts A and B, may be a more appropriate measure of cognitive inhibition than the traditional absolute time score.

The present results revealed that the prefrontal tests tap somewhat different abilities and are not redundant. Adequate assessment of prefrontal lobe abilities appears to require use of more than one test. Although few previous studies have examined the multifactorial nature of prefrontal lobe assessment, our study does contain a main limitation. Our patient sample carried primarily psychiatric diagnoses, which may somewhat limit the generalizability of our findings. Taking this limitation into account, further studies in which a similar battery of prefrontal tests are administered to different population of subjects (i.e., patients with frontal lesions, patients with extrafrontal lesions, and controls) might further clarify the findings reported here.

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