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FACTOR ANALYTIC STUDIES OF HUMAN BRAIN DAMAGE: I. FIRST AND SECOND-ORDER FACTORS AND THEIR BRAIN CORRELATES

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ABSTRACT

This report is concerned with identifying the first and second-order cognitive factors underlying a battery of 49 measures taken from 22 brain damage tests. The test scores from 176 brain damaged patients between 16 and 65 years of age were intercorrelated and subjected to first-order alpha factoring followed by promax rotation to oblique simple structure. Ten of the 13 first-order factors extracted were interpretable, six of them being perceptual in nature and four being of a more conceptual nature. The perceptual factors include: perceptual organization, perceptual-motor speed, pattern recognition, temporal resolution, spatial orientation, and figure-ground identification. The conceptual factors include verbal comprehension, memory, and two abstraction factors. A second-order alpha factoring was performed on the matrix of correlations among the 13 primaries. Three of the five second-order factors extracted were interpretable. They were identified as perceptual integration (subsuming the first-order factors of perceptual organization, perceptual-motor speed, and temporal resolution), verbal memory (subsuming verbal comprehension and memory), and visualization (subsuming spatial orientation and figure-ground identification). Although factor interpretations were based primarily on the patterns of high loading variables, they were also influenced by lesion effects observed in this and related studies. About half the interpretable factors are relatively localized (i.e., confined to one or two lobes of one hemisphere), with the other half more diffuse (i.e., multi-lobed, combined with laterality or bilaterality). The more localized factors include the right hemisphere factors of perceptual-motor speed, temporal resolution, and spatial orientation, and the left hemisphere factors of verbal comprehension, memory, and verbal memory. The more neurally diffuse factors include the second-order factors and such broad gauged first-order factors as abstraction I and II, and pattern recognition. Furthermore, same lobe, bilaterally hemispheric effects were rare, and only four factors (memory, verbal memory, visualization, and abstraction I) were correlated with sub-cortical lesions.

The search for biological correlates of behavior is an established scientific tradition which requires no special defense in spite of the need to overcome technical difficulties and in spite of the awesome complexity of the task. One subset of bio-behavioral prob-

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lems is concerned with the brain correlates of human factors of cognition. A powerful strategy for dealing with the complexities of cognitive functioning is to focus on replicable dimensions via the methods of factor analysis. This approach receives support from no less a figure than Lashley who, some three decades ago, suggested that factors seem to

> . . . *correspond to functions which may be independently lost as a result of localized brain injury*. Certain types of apraxia are marked by difficulty in dealing with spatial relations; the function represented by manipulation of isolated symbols resembles the ability which suffers in verbal aphasia—and there are other less clear correspondences.
>
> Psychology has still to discover how the varied factors revealed by such analysis interplay to produce organized thought. Neurology likewise still has much to do in the investigations of the *interaction of cortical fields which are associated with diverse functions*. Nevertheless the discovery that the various capacities which independently contribute to intellectual performance do correspond to the spatial distribution of cerebral mechanisms represents a step toward the recognition of similar organization in neurological and mental events. (Lashley, 1941, pp. 468-469; our italics).

While factor analytic research of the past thirty years has generated an enormous body of literature dealing with human cognition (e.g., see Cattell, 1966; Guilford, 1967; Royce, 1973a), very few attempts have been made to search for neural correlates of the factors isolated in these studies. In fact, in a review of the relevant literature the senior author of the present report was forced to the conclusion that there has been no sustained attack on the factor-brain correlate problem to date, and that the cumulative evidence we do have is so meager that reasonably strong claims for such correlates are demonstrable for only around a half dozen factors (Royce, 1966).

Major reasons for the past inadequate state of affairs were the uncritical proliferation of so-called brain damage tests in the first place and failure to factor analyze brain damage test batteries in the second place. While the factor strategy will not resolve all our problems in this domain of investigation, it goes a long way toward answering the question of construct validity (i.e., what the test measures). And when the factor strategy is combined with the strategy of lesion effects we can also say something about external

validity (i.e., how brain damage affects performance on a given factor). Furthermore, the factor model also provides a conceptual framework for the development of a general theory of individual differences, including behavioral deficits due to brain damage (Royce, 1973b).

This study is concerned with identifying the brain correlates of cognitive factors. It is a continuation of the research of Aftanas and Royce (1969), in which they studied the factorial composition of 29 brain damage tests administered to a normal population. Although they found that the dimensionality of the test battery was relatively complex, the majority of the tests were found to discriminate on the basis of a few dimensions. On the basis of these findings, and in connection with a survey of the literature, 22 tests were selected for studying the factorial structure of a brain damage population. More than one measure was derived from several of the tests which resulted in a total of 49 variables for analysis.[1] Seven of the tests in the present battery are common to the Halstead-Reitan test battery (Note 1) and at least two of them were used in other factor analytic studies (Aikikkala, Note 2; Bechtholdt, Benton & Fogel, 1962; Coppinger, Bortner & Saucer, 1963; Knehr, 1962; Suonio, Note 3; and Weckroth, Note 4).

The chief aims of this study are to (1) identify the cognitive factors which are being assessed via a wide ranging battery of brain damage tests, (2) identify the brain site correlates of these cognitive factors, and (3) provide a basis for the selection of improved tests of brain damage.

Subsequent reports will deal with factor score comparisons of different types of brain damage, factor score comparisons between brain damaged and normal subjects, and the relationships between age levels and factors. (Royce, Yeudall, & Wardell, Note 5). And further analysis of the individual variables used in the present

1. The fact that we have used several measures from a given test raises the issue of experimental dependence, an issue which is not well understood and a problem which will require extensive empirical investigation (e.g., see Royce, 1955, 1966; Royce, et al., 1970 for the only such research in the comparative-physiological domain). A major point is that *apparently experimentally dependent variables*, such as several measures taken from the same test or from similar-appearing ones, *are not necessarily experimentally dependent*. The key to experimental dependence is whether the measurements in question reflect the same performance. "When they do we have true experimental dependence. To the extent they do not, we have different samples of behavior which may or may not correlate, and which, therefore, manifest varying degrees of partial experimental dependence." (Royce, et al., 1970, p. 43). While we do not analyze this issue in the present report, we bring our awareness of the problem to bear on the interpretation of each factor.

study will be examined in terms of their relationship to types of brain damage, and validity for discrimination between normal and brain damaged subjects (Yeudall, Royce & Bock, Note 6).

METHOD

Subjects

One hundred and seventy-six patients (males = 163, females = 13) with established diagnoses (EEG, angiography, pneumography, and surgical notes) of brain damage due primarily to trauma, circulatory disease, or neoplasm were administered the battery of neuropsychological tests. They were between 16 and 65 years of age ($\bar{X} = 40.31$, $\sigma = 14.29$). Three patients who could not complete all the tests because of severe to moderate agnosia or dysphasia were not included in the experimental population. The patients were selected from the neurosurgical units of the University of Alberta Hospital, Edmonton, and the Workmen's Compensation Board's Rehabilitation Clinics in Edmonton, Alberta, and Downsview, Ontario.[2]

Tests and Variables

Twenty-two tests of brain damage, chosen from the previous study (Aftanas & Royce, 1969) and a literature review, were selected for analysis on the basis of the following criteria: validity, reliability, objectivity of procedure and scoring, a priori factorial simplicity, low dependence on cultural variables, and diversity. The 49 psychological variables arising from these tests and used in the present study are given in Table 1 in the order in which they were presented to the subjects.[3] Five other variables consisting of age, sex, minutes tested, handedness, and years of education were also included in the factor analysis, thus resulting in a total of 54 variables for the present study.

2. The authors wish to thank Dr. D. K. Morton, Dr. P. B. R. Allen, Dr. B. K. A. Weir and Dr. Harold Jacobs of the University of Alberta Hospital; Dr. W. F. Hall and Dr. J. R. Fowler of the Workmen's Compensation Board, Downsview, Ontario for their invaluable assistance in providing patients for this research. Over the several years of data collection the help of research assistants S. Stewart, L. Whyte, W. Young, M. Holmes, T. Frank and B. Barton is gratefully acknowledged.

3. A more detailed description of the tests and primary references can be obtained from the authors.

Table 1
Complete Set of Test Variables in the Order in Which they were Administered to Patients

Test Variables	Means
1. Wepman-Jones Test for Aphasia (errors)	8.42
2. Halstead-Speech Sounds (errors)	14.73
3. Trail Making (A) (latency)	75.85
4. Trail Making (B) (latency)	192.94
5. Memory for Designs (correct)	36.21
6. WAIS Similarities (correct)	9.15
7. WAIS Vocabulary (correct)	34.00
8. WAIS Block Design (correct)	25.70
9. WAIS Objects Assembly (correct)	24.96
10. Colored Progressive Matrices I (errors)	1.96
11. Colored Progressive Matrices II (errors)	3.17
12. Colored Progressive Matrices III (errors)	4.79
13. Finger Tapping—Preferred Hand (frequency)	43.25
14. Finger Tapping—Non-Preferred Hand (frequency)	38.35
15. Symbol Gestalt—Total Responses (correct)	35.36
16. Symbol Gestalt (errors)	10.46
17. Symbol Gestalt—Improvement (correct)	0.82
18. Symbol Gestalt—Total Weighted Score	–0.35
19. Halstead Category Test I (errors)	0.18
20. Halstead Category Test II (errors)	0.94
21. Halstead Category Test III (errors)	21.33
22. Halstead Category Test IV (errors)	20.97
23. Halstead Category Test V (errors)	18.33
24. Halstead Category Test VI (errors)	13.31
25. Halstead Category Test VII (errors)	6.77
26. Color Cognition Sorting (errors)	5.74
27. Color Cognition Memory (errors)	0.42
28. Finger Localization—Preferred (errors)	6.55
29. Finger Localization—Non-Preferred (errors)	8.31
30. Organic Integrity Test (errors)	4.74
31. Minute Estimation (time)	35.94
32. Tactual Perf. Test—Preferred (latency)	583.29
33. Tactual Perf. Test—Non-Preferred (latency)	528.58
34. Tactual Perf. Test—Both (latency)	366.70
35. Tactual Perf. Test—Localization (correct)	2.11
36. Tactual Perf. Test—Memory (correct)	5.21
37. Halstead Seashore Rhythm (errors)	9.27
38. CFF—Ascending (frequency)	43.89
39. CFF—Descending (frequency)	34.69
40. Binaural Beats (correct)	0.77
41. Retinal Rivalry (frequency)	7.64
42. Oral Word Fluency (frequency)	6.98
43. Purdue Pegboard—Preferred (correct)	11.47
44. Purdue Pegboard—Non-Preferred (correct)	10.74
45. Purdue Pegboard—Both (correct)	8.73
46. Purdue Pegboard—Assembly (correct)	23.77
47. Apparent Motion (frequency)	1.82
48. Face Hand Omissions (errors)	1.27
49. Face Hand Displacements (errors)	0.48
50. Age	40.31
51. Sex	0.92
52. Minutes Tested	320.35
53. Handedness	.6
54. Years of Education	9.00

Neurological Assessment[4]

A nine-page chart for neurological data and etiological information was completed for each patient by either a neurologist or neurosurgeon. The lesions were sketched on brain lesion charts consisting of left and right, medial, dorsal, and ventral views of the brain, as well as seven transverse sections. For 110 of the patients, the neurological charts were either made immediately after neurosurgery or reconstructed later from drawings made at the time of surgery. The remaining cases in the study were patients being evaluated for rehabilitation treatment programs. Their neurological charts were completed by a neurologist or neurosurgeon using information obtained from the neurosurgeon's notes of the operation in conjunction with data from angiography, pneumography, EEG, and brain scans. (See Table 2 for the distribution of etiological characteristics of the population.) The patients were then classified in terms of whether their damage was in any of the following twelve neurological categories: frontal, parietal, temporal, occipital, and subcortical for the left and right hemispheres; and left vs. right hemisphere.

Table 2
Etiological Categories Used for Classifying Subject

Etiology	Number of *Ss*
Cerebral vascular	10
Anoxia	2
Infections	3
Degenerative	5
Temporal lobectomy	8
Frontal lobectomy	4
Penetrating missile	8
Subdural hematoma	23
Extradural hematoma	5
Intracerebral hematoma	9
Contusion	54
Concussion	22
Glioblastoma multiforme	5
Meningioma	7
Astrocytoma	8
Oliogodendioglioma	1
Arachnoid cyst	2
Total	176

4. The authors wish to express their appreciation to Dr. O. Veidlinger, and Dr. P. B. R. Allen for their assistance in the neurological evaluation of the patients.

Procedure and Analysis

The tests were administered in a standardized order (see Table 1 for order) which was designed to maintain the interest and motivation of the patient as well as to counteract any possible fatigue effects due to the intrinsic nature of the tests. Patients were individually tested over a series of sessions, the number of which depended upon their age, nature and extent of their injury, and fatigability during any particular test session. The test battery was administered after injury to the brain had occurred with a mean time interval of 11.7 months (S.D. = 23.1) between the diagnosis or surgery and testing.

Results

The 54 measures were intercorrelated by Pearson product-moment correlations (Table 3). The correlation matrix was factored by alpha factoring (Kaiser & Caffrey, 1965) using squared multiple correlations as initial communality estimates and iterating until they converged. The alpha factors were rotated to orthogonal simple structure by the normalized varimax criterion (Kaiser, 1958), followed by promax rotations with powers 2 and 4 (Hendrickson & White, 1964). A total of 13 factors was obtained with eigenvalues greater than 1.0; the average communality was .57 for varimax.

The varimax factors are given in Table 4. The promax 2 factors are given in Table 5. Since the majority of variables identifying factors 1, 2, 4, 5, 6, 8, 9, and 10 were scored in terms of number of errors, these factors were reflected so that a high factor score is associated with better performance. These factors are reflected in Table 4. (Promax 4 was also obtained, but closely resembles the promax 2 solution, with slightly better simple structure for the latter.) The promax solution was used in the present study on the basis of previous findings (Hendrickson & White, 1964; Gorsuch, 1970; Royce, Carran & Howarth, 1970; Royce, Poley, & Yeudall, 1973; and Aftanas & Royce, 1969). The promax transformation matrix and correlations between the primary axes of the promax rotation are given in Tables 6 and 7, respectively. (Table 7 gives the intercorrelations of the factors in reflected form.)

Oblique factor scores were derived in *T*-score form by the regression method and biserial correlations were calculated between

Table 8
Product-Moment Correlations for the Fifty-Four Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	2
1																											
2	65																										
3	24	42																									
4	24	45	55																								
5	–28	–39	–47	–40																							
6	–34	–48	–39	–44	40																						
7	–47	–52	–29	–34	29	67																					
8	–27	–47	–52	–56	56	44	30																				
9	–23	–42	–51	–56	48	40	32	69																			
10	30	40	35	29	–44	–34	–22	–54	–46																		
11	29	43	48	36	–51	–44	–31	–61	–53	66																	
12	27	47	38	41	–45	–43	–34	–58	–47	55	70																
13	–14	–25	–17	–18	35	22	17	26	25	–21	–22	–16															
14	–07	–21	–19	–24	25	06	01	20	22	–17	–19	–24	57														
15	–26	–41	–56	–62	49	42	28	57	53	–37	–36	–42	33	28													
16	38	44	22	40	–33	–33	–27	–44	–42	42	44	38	–16	–24	–24												
17	–16	–15	–16	–16	11	08	08	07	13	–09	–15	–10	10	00	27	–07											
18	–42	–49	–40	–43	38	34	35	51	46	–40	–44	–36	26	26	58	–65	32										
19	23	32	35	14	–25	–21	–19	–27	–22	19	22	22	–10	–03	–28	22	–07	–34									
20	09	35	31	26	–15	–23	–15	–28	–28	26	24	20	–26	–20	–27	20	–08	–34	29								
21	02	09	11	19	–12	–03	–00	–31	–23	20	24	22	–04	–14	–16	10	07	–08	07	17							
22	14	27	29	44	–32	–40	–29	–52	–47	31	42	40	–16	–20	–42	28	–01	–29	14	11	35						
23	06	27	25	24	–34	–28	–16	–47	–43	35	39	36	–20	–20	–32	32	03	–32	23	28	20	34					
24	13	31	28	29	–38	–29	–20	–58	–47	42	45	47	–19	–20	–41	36	01	–38	22	31	18	43	76				
25	09	27	34	34	–40	–22	–05	–56	–51	38	47	43	–22	–28	–41	27	–02	–25	18	25	42	53	58	65			
26	28	40	41	21	–37	–28	–26	–48	–44	40	39	30	–17	–16	–32	32	–11	–44	59	30	25	23	37	31	37		
27	30	44	32	19	–14	–43	–45	–22	–25	08	17	24	–16	–03	–21	16	–11	–21	51	15	–03	22	08	15	11	39	

Table 3 (Continued)
Product-Moment Correlations for the Fifty-Four Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	2
28	20	46	38	36	–40	–23	–24	–46	–42	26	36	33	–16	–13	–42	30	–12	–44	39	36	23	25	38	37	47	47	3
29	12	35	41	47	–32	–21	–14	–40	–43	30	43	36	–09	–37	–36	39	–10	–44	32	31	28	35	39	36	46	39	1
30	24	33	28	37	–27	–32	–19	–46	–34	40	35	38	–21	–15	–46	29	–10	–33	18	23	08	28	14	22	28	24	1
31	–29	–23	–07	–15	23	23	28	16	15	–23	–28	–22	06	17	13	–33	00	19	–16	04	–18	–32	–15	–19	–23	–14	–1
32	08	34	38	51	38	–30	–13	–50	–47	29	32	32	–26	–27	–52	27	–16	–34	04	28	11	26	32	34	39	18	0
33	13	31	42	46	–44	–28	–12	–54	–55	34	51	38	–17	–29	–47	39	–15	–41	11	30	22	38	38	44	41	26	0
34	11	32	50	49	–44	–30	–07	–55	–60	40	41	33	–26	–32	–51	29	–16	–34	16	36	22	32	41	42	50	31	0
35	–05	–17	–34	–33	33	24	05	48	40	–32	–32	–32	15	12	41	–24	19	29	–13	–21	–19	–36	–30	–32	–34	–23	–0
36	–19	–35	–42	–38	42	34	20	49	43	–39	–44	–42	12	16	37	–31	13	32	–23	–32	–17	–37	–31	–31	–35	–27	–1
37	26	41	30	31	–43	–39	–31	–41	–36	40	32	28	–18	–15	–36	24	–05	–29	16	24	05	15	18	14	17	31	1
38	14	18	05	–01	01	–10	–18	–03	–04	03	09	09	–03	–02	–03	11	–22	–11	–06	07	–24	–11	–07	–03	–14	05	0
39	–07	–06	–11	–14	13	08	03	06	07	–00	–06	–04	30	12	13	–16	14	20	–06	–27	16	14	02	–01	04	–11	–0
40	–12	–26	–26	–24	13	20	05	26	29	–27	–30	–23	02	08	23	–03	10	19	–11	–26	–16	–05	–15	–15	–24	–29	–0
41	–15	–18	–24	–27	23	11	01	17	32	–21	–19	–25	31	24	38	–20	19	26	–13	–20	–13	–15	–18	–20	–26	–20	–1
42	–36	–55	–32	–45	42	50	49	41	35	–28	–29	–35	26	16	45	–30	14	40	–16	–24	–13	–35	–22	–27	–19	–24	–4
43	–18	–33	–43	–42	43	23	04	48	30	–30	–34	–25	34	26	47	–26	14	32	–30	–21	–13	–21	–34	–34	–39	–36	–1
44	–16	–31	–36	–35	33	08	–04	42	36	–29	–36	–29	16	45	41	–26	18	35	–13	–19	–25	–26	–31	–34	–40	–31	0
45	–15	–30	–36	–39	34	06	–10	43	40	–28	–33	–28	13	37	44	–26	23	34	–11	–23	–25	–26	–29	–32	–41	–28	0
46	–12	–36	–47	–56	32	18	–03	54	53	–35	–38	–35	24	41	56	–38	21	46	–21	–26	–21	–32	–31	–35	–45	–36	–1
47	–08	02	16	06	–10	–00	08	–11	–08	06	09	09	07	–15	–13	–06	10	–04	03	12	11	05	–02	01	12	10	–1
48	02	15	24	33	–12	–08	–07	–18	–15	25	22	23	02	–14	–13	25	07	–12	17	20	12	09	16	14	14	18	–0
49	09	26	34	25	–29	–25	–14	–38	–34	36	35	25	–13	–05	–27	26	–08	–40	26	44	18	18	31	29	32	46	1
50	–01	16	17	35	–30	–25	06	–30	–25	24	20	30	–24	–27	–40	26	02	01	09	19	12	24	20	26	30	05	0
51	09	09	07	10	–06	–15	01	–11	–08	–01	–04	02	–07	05	–13	14	–11	–15	–02	08	03	03	02	05	07	08	1
52	12	32	28	29	–27	–19	–21	–28	–23	26	22	21	–28	–43	–26	31	–06	–30	12	18	–07	13	21	29	17	22	1
53	12	05	–02	04	01	–09	–12	–09	05	09	00	–02	06	02	03	04	10	–05	00	–04	–10	07	05	09	–08	–03	0
54	–37	–39	–09	–21	18	45	48	19	13	–13	–15	–27	13	15	22	–23	10	22	–04	–13	–05	–26	–11	–18	–11	–03	–2

Table 3 (Continued)
Product-Moment Correlations for the Fifty-Four Variables

	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
28																											
29	59																										
30	19	21																									
31	−14	−18	−12																								
32	35	32	37	−01																							
33	32	48	30	−18	62																						
34	38	48	33	−05	68	78																					
35	−23	−28	−36	06	−38	−54	−52																				
36	−29	−35	−37	14	−42	−52	−57	57																			
37	33	23	28	−09	31	32	35	−19	−39																		
38	−10	02	20	−11	19	10	02	−06	01	−01																	
39	−06	09	−08	−05	−16	−13	−07	04	03	−12	−03																
40	−23	−31	−16	−06	−18	−26	−34	17	28	−29	−02	14															
41	−20	−21	−19	08	−27	−28	−28	31	21	−13	−07	18	−04														
42	−36	−21	−29	21	−35	−31	−25	14	32	−39	−04	11	09	13													
43	−41	−35	−27	06	−37	−28	−43	21	27	−30	−09	08	17	25	35												
44	−30	−51	−24	15	−38	−56	−55	30	36	−26	−04	02	27	22	22	59											
45	−35	−49	−28	08	−36	−50	−54	25	34	−26	07	02	28	18	25	68	86										
46	−39	−58	−33	12	−53	−54	−60	37	37	−28	−02	13	32	32	26	57	70	73									
47	10	16	03	08	09	10	19	−04	−16	15	−06	07	26	05	08	−11	−19	−25	−19								
48	19	48	11	−10	17	20	24	−08	−11	17	01	01	−18	−12	−09	−13	−24	−22	−32	00							
49	52	47	22	−07	24	28	33	−13	−21	23	−04	−17	−22	−13	−18	−22	−16	−17	−30	10	28						
50	14	19	35	−16	34	34	38	−35	−31	25	02	−05	−05	−34	−12	−29	−20	−27	−31	02	09	02					
51	01	−05	03	08	11	09	15	−15	−08	05	−02	−07	04	−18	−18	−21	−05	−06	−08	−16	−12	06	12				
52	18	28	22	−05	37	31	35	−15	−20	−23	26	−11	−05	−26	−24	−27	−34	−26	−28	03	11	07	22	03			
53	04	05	−04	−04	03	−02	−14	09	06	00	−03	02	08	−23	−10	06	−01	03	02	−02	11	01	−20	−18	11		
54	−03	−01	−23	19	−19	−09	−05	05	23	−21	−12	03	−01	07	38	01	02	01	06	06	08	01	−18	−00	−19	−13	

Table 4
Thirteen Varimax Factors for Fifty-four Variables

Variables	Communalities	1	2	3	4	5	6	7	8	9	10	11	12	13
1	54	−05	61	−17	13	28	−02	01	02	−04	02	09	−20	−05
2	70	15	67	−23	26	18	12	−07	14	13	00	12	−08	−06
3	55	51	17	−17	39	13	−02	−08	12	16	−03	−03	−11	05
4	73	62	33	−19	07	02	−10	−14	35	−02	08	−15	−10	05
5	52	−41	−25	19	−19	−38	−10	20	01	−02	01	11	−02	−02
6	62	−38	−63	−12	−18	−15	−07	04	−01	−03	01	03	−04	−03
7	69	−12	−73	−19	−20	−10	−03	02	−02	01	−07	−07	07	−18
8	75	−59	−26	19	−18	−37	−30	04	−05	−08	−05	13	03	−07
9	58	−55	−20	15	−21	−24	−21	−09	−10	−09	−10	08	14	04
10	62	30	19	−10	08	63	20	−05	16	12	03	02	01	01
11	71	36	20	−08	16	62	18	−07	11	16	19	03	−12	05
12	53	39	28	−04	13	43	14	−08	10	10	21	05	−01	−02
13	62	−15	−14	06	−09	−11	−09	73	08	04	05	04	04	07
14	68	−08	−08	31	06	−00	−10	65	−11	−10	−20	−11	−11	02
15	68	−64	−24	22	−22	−10	02	25	−01	−04	−07	09	18	02
16	60	15	35	−19	02	37	26	−09	37	−21	02	11	−09	−12
17	36	−18	−07	12	−07	−01	10	03	08	04	05	−18	49	13
18	69	−23	−36	23	−19	−24	−23	15	−20	01	04	−05	49	01
19	56	05	12	−05	70	12	08	−01	13	04	03	09	01	−06
20	50	19	16	04	19	−04	30	−24	29	33	−14	02	−08	−18
21	43	11	02	−10	01	07	18	02	13	18	46	−28	01	−18
22	62	44	27	−05	06	11	20	−03	01	−06	51	−16	02	09
23	63	29	05	−12	18	17	66	−08	07	−03	11	−06	06	06
24	73	36	10	−12	15	20	68	−11	01	−06	14	−02	03	10
25	70	39	01	−19	16	18	47	−15	08	11	89	−18	02	−09
26	62	10	15	−16	59	27	24	−05	18	19	01	−01	−12	−11
27	63	06	46	04	62	−11	00	−04	−05	−11	06	06	−03	02
28	54	24	18	−18	44	06	27	−06	26	15	05	−18	−13	01
29	75	29	04	−34	28	04	20	−03	55	18	28	05	−07	07
30	33	41	23	−07	06	24	01	−10	06	07	02	14	00	−09
31	33	01	−27	06	−06	−26	−04	04	−12	16	−37	−08	−03	−01
32	61	65	16	−20	−04	−04	19	−18	13	08	−12	12	−04	01
33	65	61	11	−27	−06	08	29	−06	22	12	05	12	−10	−08
34	76	67	04	−32	04	03	27	−08	16	24	−03	06	−00	−17
35	52	−62	01	04	−01	−15	−16	−03	−00	−03	−09	−10	07	23
36	52	−53	−24	12	−06	−19	−15	−06	−04	−24	−06	−06	−04	17
37	46	27	37	−16	08	26	−01	−07	10	26	−21	−08	12	−06
38	46	07	12	05	04	04	−07	−02	−00	−04	−07	64	−13	00
39	33	−06	−06	−08	−00	−04	−00	36	−10	−04	34	01	23	10
40	38	−19	−06	11	−10	−12	−04	−02	−12	−52	05	02	11	07
41	38	−29	00	09	−12	−08	−02	32	−10	11	−06	−08	11	34
42	57	−28	−64	15	−14	−02	−07	11	−05	07	03	14	06	−01
43	71	−32	−08	60	−32	−15	−07	18	03	04	12	21	−04	09
44	80	−29	−01	77	−02	−10	−14	10	−12	−17	−14	−09	08	01
45	85	−31	−01	81	−03	−09	−08	06	−10	−20	−09	06	10	04
46	73	−48	−02	55	−12	−08	−06	18	−28	−13	−09	01	16	04
47	32	09	−10	−16	02	02	−04	00	−03	50	06	−04	10	11
48	48	14	−04	−10	10	13	−02	01	62	04	04	02	10	12
49	52	17	06	04	29	17	29	−07	39	21	−08	−18	−21	−02
50	60	46	05	−09	−04	13	−02	−02	08	−08	10	08	39	−36
51	31	12	12	−10	01	−10	08	01	−07	−21	−16	−13	−09	−40
52	47	24	18	−27	08	02	16	−32	09	−04	−12	35	11	11
53	33	−07	16	−03	−04	−00	10	06	10	−07	−06	−00	03	51
54	47	−11	−62	−06	10	−00	−06	12	09	01	−12	−13	−03	−04

Table 5
Promax Factors
Pattern on the Primary Axes

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
1	17	–59	–16	–07	–24	11	04	03	03	–02	06	–20	–03
2	–00	–65	–18	–20	–09	–01	00	–07	–15	01	09	–05	–04
3	–47	–05	–09	–32	–09	06	00	–08	–12	05	02	–07	06
4	–63	–24	–09	04	05	17	–04	–35	06	–09	–15	–04	04
5	31	11	10	09	37	07	14	–07	–01	–04	10	–03	03
6	33	58	–19	11	11	03	–03	–03	05	–00	03	–07	–02
7	07	71	–22	14	06	–01	–01	–00	01	08	–07	07	–18
8	49	12	09	06	33	28	–06	–02	04	03	10	03	–08
9	46	08	05	10	19	17	01	04	06	10	06	11	04
10	–15	06	00	04	–64	–13	00	–08	–08	01	02	01	03
11	–22	–05	02	–03	–63	–11	–03	–03	–11	–15	04	–13	08
12	–27	–17	06	–04	–41	–08	–04	–04	–07	–19	05	00	–02
13	03	03	–02	02	08	06	74	–13	–03	–05	03	05	06
14	–06	04	33	–08	–05	03	67	07	10	18	–08	–10	00
15	60	11	13	12	04	–06	18	–03	01	07	05	16	02
16	–00	–26	–10	07	–32	–17	01	–35	24	–00	05	–07	–12
17	18	02	11	03	–00	–12	–01	–11	–04	–05	–21	49	11
18	11	25	16	04	19	15	07	13	–03	–04	–05	49	–04
19	06	–04	01	–72	–06	–06	03	–12	–02	–00	12	05	–07
20	–06	–14	13	–12	12	–20	–20	–23	–35	11	00	–04	–15
21	–02	–05	–06	04	–01	–10	00	–11	–17	–50	–33	04	–20
22	–40	–22	03	01	–05	–20	–01	01	09	–52	–16	02	05
23	–15	04	–03	–11	–11	–69	–02	–02	05	–10	–04	05	05
24	–22	–00	–03	–07	–15	–73	–04	05	09	–12	02	00	10
25	–25	07	–09	–09	–11	–45	–11	04	–08	–39	–18	03	–10
26	07	–06	–09	–54	–20	–18	00	–07	–17	01	01	–09	–09
27	–01	–42	06	–65	20	–00	01	04	09	–06	08	00	–01
28	–13	–11	–11	–35	02	–21	00	–23	–12	–06	–16	–10	03
29	–19	02	–24	–22	05	–11	03	–55	–13	–26	03	–03	08
30	–34	–14	01	–01	–23	04	–04	–01	–06	01	14	03	–10
31	–08	24	02	04	23	–00	04	13	–18	35	–04	–03	02
32	–62	–07	–11	11	10	–18	–08	–08	–06	13	15	–02	02
33	–54	–03	–17	13	–01	–24	04	–15	–09	–04	12	–07	07
34	–58	03	–22	01	04	–22	03	–08	–23	04	07	04	–16
35	59	–11	–05	–03	12	15	–12	–05	01	07	–12	04	26
36	45	19	04	01	14	09	–14	–03	24	05	–06	–08	17
37	–17	–33	–11	–01	–23	10	–01	–03	–27	22	–10	16	–03
38	–06	–07	05	–09	–04	07	00	02	03	13	66	–14	01
39	01	–01	–13	–07	05	–04	34	07	05	–32	00	21	06
40	11	05	08	03	10	–06	–03	05	52	–05	02	09	01
41	22	–10	00	10	03	–03	27	09	–13	06	–07	06	37
42	21	61	11	05	–06	01	03	01	–06	–01	16	03	–01
43	21	–01	56	28	08	04	09	–08	–07	–14	20	–07	09
44	17	–02	75	–02	03	07	04	05	13	10	–08	08	–03
45	20	–02	79	–02	02	–00	00	02	17	07	07	09	00
46	40	–07	47	05	01	–02	10	23	08	07	00	13	01
47	–06	07	–18	–01	–02	08	–04	08	–50	–05	–03	09	15
48	–11	10	–02	–06	–11	09	06	–67	02	–01	–01	15	12
49	–06	03	14	–17	–13	–21	–02	–36	–18	07	–18	–18	01
50	–39	02	01	01	–08	06	–18	–06	08	–07	04	46	–43
51	–09	–13	–09	–01	–15	–06	08	09	19	12	–16	–05	–42
52	–15	–10	–22	–09	02	–16	–27	–05	04	17	37	11	12
53	03	–16	–05	08	–02	–14	06	–12	08	08	03	–02	54
54	06	64	–06	–13	–04	03	11	–13	03	14	–10	–02	–04

factor scores and the presence or absence of damage in 12 neurological categories. Documented damage was scored 1; absence of damage was scored 0. Since all factors are reflected so that higher ability is indicated by a higher factor score, the correlations with damage given in Table 8 are largely negative; that is, low factor scores are associated with neurological damage. On the other hand, the interpretation of a positive correlation is that brain damage is associated with high factor scores. The obtained findings between factors and areas damaged will be discussed, keeping in mind the limitations imposed by the skewed distributions on many neurological categories (see Table 8).

Table 6
Transformation Matrix
to Reference Structure Solution

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
1	96	–13	11	–05	–02	04	11	–02	–04	–02	07	04	–04
2	–07	96	–01	–05	–06	–09	03	–04	06	04	–06	02	01
3	08	–02	98	–01	06	04	–05	04	03	04	02	01	–04
4	–06	–09	08	97	–06	02	03	02	–02	–03	07	04	–03
5	–12	–15	06	–11	99	–05	00	–05	–07	–07	–01	–02	02
6	–15	00	05	–04	–06	97	04	–07	02	02	01	–05	02
7	10	10	–07	05	01	03	98	03	–02	–01	00	02	–02
8	–03	–02	10	–05	–04	–13	06	99	–05	00	–08	08	00
9	–09	09	–02	–03	00	–11	–08	–11	99	02	00	01	09
10	–03	04	01	02	–04	–02	–08	02	–02	99	–04	02	–05
11	–02	–03	–01	12	00	02	01	–02	02	–09	98	–02	00
12	–02	04	01	14	–01	03	00	04	02	–05	–04	99	–08
13	11	–05	–04	–05	06	12	–04	04	–04	–04	10	–10	99

Table 7
Correlations Between Primary Axes

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.0												
2	.27	1.0											
3	–.24	–.06	1.0										
4	.20	.19	.06	1.0									
5	.27	.29	.20	.24	1.0								
6	.22	.18	.18	.10	–.22	1.0							
7	.28	.22	.18	.14	.14	.17	1.0						
8	.17	.14	.22	.10	.20	.26	–.17	1.0					
9	.14	–.08	.07	.07	.11	.15	.04	.20	1.0				
10	.00	–.07	.04	.01	.09	.00	.10	–.02	.00	1.0			
11	.06	–.05	–.02	.20	.00	.03	.00	–.07	.02	–.13	1.0		
12	.08	.10	.02	.20	.05	.05	.04	.15	.07	–.09	.08	1.0	
13	.14	.05	.14	–.02	.13	.18	.12	.13	.10	–.08	–.09	.18	1.0

Table 8
Biserial Correlations of Factors With Neurological Sites

Site	$\bar{X}$	S.D.	Factor (First Order) I	II	III	IV	V	VI	VII	VIII
1 Right Hemisphere	.60	.49			–23	(+17)		–46	–18	
2 Left Hemisphere	.55	.50			(+38)	–20		(+27)		(+17)
3 Right Frontal	.38	.49			–21			–50		–16
4 Right Parietal	.27	.45			–29	(+26)		–15	–25	–24
5 Right Temporal	.24	.43	–27	(+18)		(+20)		–22	–22	
6 Right Occipital	.06	.25			(+20)			–29		
7 Right Subcortical	.15	.35						–29		
8 Left Frontal	.35	.48		–19	(+22)		(+24)	(+16)		(+14)
9 Left Parietal	.23	.42	–18				–18	(+17)		
10 Left Temporal	.29	.46		–18	(+32)	–24		(+31)		(+16)
11 Left Occipital	.07	.26		(+27)			–49	–25		
12 Left Subcortical	.10	.30				–40				

Site	IX	X	XI	XII	XIII	Factor (Second Order) I	II	III	IV	V
1 Right Hemisphere			17	–17	–33	–18		–30	31	
2 Left Hemisphere		(+21)	–27		27	(+18)	–14	(+30)	38	–14
3 Right Frontal	–20	–22		–20	–24	–17		–39	17	
4 Right Parietal		–35	23			–27	(+20)		30	25
5 Right Temporal	(+21)			18		–17	(+18)			
6 Right Occipital			–30			(+16)				
7 Right Subcortical				–53	–16			–21	17	–34
8 Left Frontal		(+24)						(+27)		–31
9 Left Parietal			–35		16				–40	
10 Left Temporal	(+25)				35	(+16)	–18	(+39)	–29	
11 Left Occipital	–22		–18					–22	–24	32
12 Left Subcortical		(+19)	–29	–16		(+15)	–25		–42	–17

Interpretation of Factors and Correlations With Brain Loci

Factor 1. The interpretations of the promax 2 factors are based on primary pattern loadings of .30 or greater on this factor. They are:

4	Trail Making B	–.63
32	Tactual Performance Test—Preferred Hand	–.62
15	Symbol Gestalt—Total Responses	.60
35	Tactual Performance—Localization	.59
34	Tactual Performance Test—Both Hands	–.58
33	Tactual Performance Test—Non-preferred Hand	–.54
8	WAIS—Block Design	.49
9	WAIS—Object Assembly	.46
3	Trail Making A	–.46
36	Tactual Performance Test—Memory	.44
46	Purdue Peg Board—Assembly	–.40
22	Halstead Category—Test IV	–.40
50	Age	–.39
30	Organic Integrity Test	–.34
6	WAIS—Similarities	.33
5	Memory For Designs	.31

This factor is interpreted as *perceptual organization.* The factor may be characterized as an ability to integrate or organize the relevant aspects of the perceptual field in relation to the appropriate motor behavior. This factor appears to be the same as the first factor extracted by Aftanas and Royce (1969) using a normal population. Two measures of perceptual organization (the Block Design and Object Assembly subtests of the WAIS) were added to the revised test battery and their loadings on this factor lend further support to this interpretation.

This factor's highest correlation is with damage to the temporal regions of the right hemisphere and parietal areas of the left hemisphere. The higher correlation with the right hemisphere is in agreement with the growing evidence that visuo-spatial disorders are more prominent in patients with right hemisphere damage (McFie, Piercy, & Zangwill, 1950; Reitan, 1959, 1959b; Gloning, Gloning, & Hoff, 1968; Piercy & Smyth, 1962, and Warrington, 1969). The obtained correlations are in conformity with the findings of Reitan (1964) and Teuber & Weinstein (1954), which implicated the temporal and parietal areas as well as the frontal regions of the brain as contributing to impairment on the Tactual Performance Test (which had the highest loadings on Factor 1)

Tests involving both visual and somesthetic senses load on this factor, indicating that perceptual organization is not modality-specific. This finding is consistent with the earlier reports of Semmes, Weinstein, Ghent & Teuber (1955), and Semmes (1965) where they also identified tasks involving the same ability which were not modality-specific. In a recent review of constructional apraxia Warrington (1969) concluded that the evidence supports laterality effects for these functions, with the right hemisphere subserving primarily a perceptual function and the left subserving primarily an executive function. Following this line of reasoning the variables with high loadings would appear to be more perceptual than executive in nature since this factor shows a higher correlation with damage to the nondominant hemisphere.

Factor II. Seven variables have loadings of .30 or above on this factor. They are:

7	WAIS—Vocabulary	.71
54	Years of Education	.64
2	Speech Sounds Perception	–.64
42	Oral Word Fluency	.61
1	Wepman-Jones Aphasia	–.59
6	WAIS—Similarities	.58
27	Color Memory	–.42
37	Seashore Rhythm	–.33

This factor is interpreted as *verbal comprehension.* Six of the seven variables loading on this factor involve encoding and/or decoding of verbal material, and the seventh variable (37) involved encoding and/or decoding of rhythmic beats. The two WAIS subtests loading on this factor are consistently found to have high loadings on verbal factors identified in other studies (Cohen, 1957; Lansdell, 1968c and 1971). This factor clearly represents a verbal factor and is similar to the factor extracted by Goldstein & Shelly (1972). The loading of variable 37 is not consistent with a verbal comprehension interpretation of this factor (Kimura, 1964, and Milner, 1962, 1967). This loading is, however, very low, and probably reflects its communality with the other variables in terms of auditory processing rather than phonetic or verbal symbolic processing (Shankweiler, D., 1966, and Studdert-Kennedy, Shankweiler & Pisoni, 1972). The loading of "years of education" is consistent with the frequently reported correlation between verbal abilities and attained level of education (Wechsler, 1958).

Poor verbal comprehension is associated with damage to the temporal and frontal areas of the left hemisphere. Since only right-handed patients were included in this analysis, the correlation with left temporal and frontal damage is congruent with the evidence that verbal functions are primarily mediated by the dominant hemisphere (Costa & Vaughan, 1962; Dennerl, 1964; Lansdell, 1968b, 1968c; Milner, 1962, 1967; Russell & Espir, 1961; Vignolo, 1969; and Zangwill, 1964). In addition, verbal comprehension appears to be better in those with right temporal or left occipital damage.

Factor III. Five variables have significant loadings on this factor. They are:

45	Purdue Peg Board—Both	.79
44	Purdue Peg Board—Non-Preferred	.75
43	Purdue Peg Board—Preferred	.56
46	Purdue Peg Board—Assembly	.47
14	Finger Tapping—Non-preferred	.33

Even though four of the five variables loading high on this factor are experimentally dependent, this factor is tentatively interpreted as *perceptual-motor speed.* A similar factor was extracted from a normal population of subjects by Aftanas and Royce (1969). However, that factor was identified by other measures which seem to be characterized more by perceptual rather than motor components.

Although speed of both motor and perceptual processing is involved in this factor, it is our view that the perceptual aspect of the factor is manifested primarily via the Purdue Peg Board measures and that Finger Tapping is primarily a motor indicator. The low loading of Finger Tapping (.33) is consistent with this interpretation on the grounds that Finger Tapping requires little or no perceptual processing. Furthermore, the absence of a significant loading for preferred hand Finger Tapping suggests that this factor is related to functions of the non-dominant hemisphere (i.e., the right hemisphere in most cases). However, the most convincing evidence for this interpretation comes from our brain damage data —namely, that poorer perceptual-motor speed is associated with damage to the right hemisphere (frontal and parietal regions).

Several non-factorial studies involving the Purdue Peg Board also report performance impairment due to right hemisphere lesions (Costa, Vaughan, Levita, & Farber, 1963; Costa, Vaughan, Horowitz, & Ritter, 1969; Gazzaniga, Bogen, & Sperry, 1964; Sperry, Gazzaniga, & Bogen, 1969; Vaughan & Costa, 1962). In all cases the authors conclude that right hemisphere damage resulted in significantly poorer performance than left hemisphere damage. However, since Vaughan and Costa's interpretation is that Purdue Peg Board performance is mediated via a relatively diffuse sensory-motor system, whereas Sperry, et al. put more stress on visuo-spatial processing, the issue of the importance of the motor aspect of the peg board measures requires further investigation. Factor analysis of a more extensive battery of perceptual and motor tasks (e.g., less experimentally dependent than in the present case) is an obvious step which needs to be taken.

Factor IV. Four variables have loadings of .30 or higher on this factor. They are:

19	Halstead Category Test 1	–.72
27	Color Memory	–.64
26	Color Sorting	–.54
28	Finger Localization—Preferred	–.35
3	Trail Making—A	–.32

This factor is tentatively interpreted as *memory*. This factor is characterized by the retrieval of long-term memories from permanent storage. It is hypothesized that the memory component common to these variables is of a more "primitive" nature in terms of associative memory processes. That is, the formation of the memories involves the simple association of a thing or unit with an invariant label (e.g., name of fingers, color of fruits, and Arabic equivalents of Roman numerals). The relative simplicity of level of psychological complexity is exemplified by the loading of the first subtest of the Halstead Category Test. This subtest was included in the Category Test with the intention of familiarizing the subject with the procedure and was not included as a discriminating brain damage variable.

Poor memory ability is associated with left temporal damage and subcortical damage to the underlying white matter of the left cerebral hemispheres. Furthermore, these data indicate that memory is enhanced when there is damage to temporal and parietal regions of the right hemisphere. Of the 38 cases with major underlying damage to the white matter, 42% involved the temporal lobes and 47% the frontal lobes, whereas the remaining cases involved damage to the parietal and occipital areas of the brain. This finding is consistent with the research implicating subcortical integration in learning and memory (Barbizet, 1969; Smythies, 1966; Levita & Riklan, 1965; Terzian & Dalle Ore, 1955).

Factor V. Five variables have loadings of .30 or higher on this factor. They are:

10	Ravens Colored Progressive Matrices I	–.64
11	Ravens Colored Progressive Matrices II	–.63
12	Ravens Colored Progressive Matrices III	–.41
5	Memory-For-Designs	.36
8	WAIS—Block Design	.33
16	Symbol-Gestalt (errors)	–.32

This factor is tentatively interpreted as *pattern recognition*. It is somewhat underdetermined due to experimental dependence of variables 10, 11 and 12. This interpretation assumes we are dealing with a more primitive cognitive process involved in the identification and short-term retention of contours and configural patterns of visual stimuli as contrasted to similar tasks involving more complex cognitive processes (e.g., as in Object Assembly subtests of the Wechsler Scale where the patient has to rotate or orient the stimulus materials to produce a meaningful stimulus configuration). Block Design is also a complex cognitive task; however it differs from Object Assembly in that the design to be constructed is done from a model and is thereby similar to the other variables loading on this factor. In variables 10, 11, 12, and 16 the task involves simultaneous perceptual matching of visual figures, whereas variable 5 requires matching from immediate memory (5 seconds delay).

In a more cognitive framework this factor has similarities to Guilford's (1967) Cognition of Figural Relations factor. Although the Memory-For-Designs Test implicates memory, the nature of the designs suggests that it is the ability of the subject to store the relationships between various aspects of the stimulus complex which is crucial in solving this task. To the extent that solving figure analogy tasks is involved in the Memory-For-Designs and the other measures of pattern recognition, such as the Ravens Matrices and Symbol Gestalt, there is a linkage to Guilford's CFR factor.

Poor pattern recognition is associated with damage to the left parietal and occipital areas while pattern recognition is better for those with damage to the left frontal region. The correlation of this factor with only the left hemisphere is not consistent with the findings of several researchers (Costa, Vaughan, Horowitz, & Ritter, 1969; Colonna & Faglioni, 1966; De Renzi & Faglioni, 1965; and Piercy & Smyth, 1962) who found bilateral temporal lobe impairments for the Ravens Progressive Matrices.

Factors VI and X (Halstead Abstraction I and II). Three variables have loadings of .30 or higher on Factor VI. Five variables have loadings of .30 or higher on Factor X.

Halstead Abstraction I		*Halstead Abstraction II*	
24 Halstead Category Test - VI	–.74	23 Halstead Category Test - IV	–.52
23 Halstead Category Test - V	–.69	21 Halstead Category Test - III	–.50
25 Halstead Category Test - VII	–.45	25 Halstead Category Test - VII	–.39
		31 Minute Estimation	+.35
		39 CFF - Descending	–.32

These factors are tentatively interpreted as *Halstead Abstraction I and II*. Performance on the Halstead Category Test in most studies has been depicted by a single error score based on the sum of errors for the seven subtests. The structure of the category test consists of a series of seven subtests which progress from simple recognition of Roman numerals to more complex subtests of concept formation utilizing multiple cues such as color, shape, size, and spatial orientation. The last subtest (variable 25) is a memory variable which consists of items from the other subtests. Subtests I and II involve the recognition of figural and symbolic units whereas the solutions to subtests III, IV, V, and VI would appear to involve abstract thinking. The separation of the latter variables on Factors VI and X suggests further differentiation of the Halstead Category Test. Subtests III and IV consist of a series of oddity problems in which the spatial position is the key to the solution of the test. In subtests V and VI the spatial position or orientation of the stimulus is irrelevant; however, the configuration of the stimulus has to be represented numerically, i.e., the relevant component of the stimulus complex is equal to some proportion of the total stimulus. It would appear that the separation of these two abstraction factors (involving convergent, *not* divergent thinking) can be conceptualized in terms of the symbolic transformation (Guilford's CFT) that has to be made by the subject in the tasks loading on Abstraction I. It is also assumed that Abstraction II (Guilford's CFC) is less complex, as the solution is dependent upon the mere cognition of classes (i.e., does not involve any transformations). The finding that the subtests of the Halstead Category Test load on Factors VI and X is consistent with Haynes and Sell's (1963) point that "abstraction must be considered as a multidimensional function with many modes of expression."

Poor scores on Factor VI (Halstead Abstraction I) correlates with damage to the frontal, temporal, pariental, occipital, and subcortical regions of the right hemisphere. Better performance is correlated with damage to the frontal, temporal and parietal regions of the left hemisphere. Poor scores on Factor X (Halstead Abstraction II) correlates with damage to only the frontal and parietal regions of the right hemisphere. Better performance is correlated with damage to the frontal and subcortical regions of the left hemisphere. These findings are consistent with Chapman and Wolff's (1959), and Shure and Halstead's (1958) findings that damage to non-frontal areas also resulted in the impairment of abstractive abilities and that damage to the right hemisphere resulted in more errors on the category test. Similar results were also obtained by Doehring and Reitan (1961); they report poorer performance on the category test by right hemisphere patients. However, in a later study (Doehring & Reitan, 1962) they did not find the right hemisphere effect to be significant, although it was still in the same direction as their previous findings. Lansdell (1968a) has also found evidence to suggest that abstract reasoning is symmetrical in regard to temporal lobe involvement; however, his measure of abstraction (AR subtest from the DAT) correlates significantly ($r = .51, p > .01$) with vocabulary measures which are known to be impaired by dysfunction of the left temporal lobe (Lansdell, 1968b, 1968c; and Milner, 1967). As the subtests loading on these two factors did not significantly correlate with the WAIS vocabulary subtest, the finding that these two factors correlated primarily with damage to the right hemisphere is consistent with the evidence relating impairment on non-verbal figural tasks to dysfunction of the non-dominant hemisphere.

The correlations of Factor VI (abstraction I), indicating bilateral relationships as well as more areas of the brain compared to Factor X, are consistent with the present factor interpretation of Halstead abstraction I. That is, the nature of the variables identifying this factor were considered to be more factorially complex and consequently would be less localized and lateralized. These findings are consistent with the hypothesis of Teuber & Weinstein (1954) and Lansdell (1968a), which allows for both focal and generalized effects of brain injury, depending upon the particular psychological functions or processes being tapped by a given test. This approach is similar to the "functional" position regarding the localization of cerebral processes (Luria, 1966; Frederiks, 1969; and Hécaen, 1969).

The psychological relationship of variables 31 and 39 to Factor X is not readily apparent. It can only be assumed that the same neurological processes may be involved in the solution of the three subtests loading on this factor.

Factor VII. Three variables have loadings of .30 or higher on this factor. They are:

13	Finger Tapping—Preferred Hand	.74
14	Finger Tapping—Non-Preferred Hand	.67
39	CFF—Descending	.34
41	Retinal Rivalry	.28

This factor is tentatively interpreted as *temporal resolution.* It is hypothesized that this factor reflects the efficiency of the brain, or selected areas of the brain, in the processing of convergent temporal information from different sensory modalities (Jones & Powell, 1970 and Kreig, 1963). The involvement of different sensory modalities in this factor indicates that higher cerebral processing of sensory information is involved rather than activity in peripheral or primary sensory areas. This factor bears resemblance to Halstead's (1947) Power factor; Shure and Halstead's (1958) Psychological Vigilance factor; Coppinger, Bortner & Saucer's (1963) Sensory Alterness factor; Honigfeld's (1962) Neurological Efficiency factor, and Aftanas and Royce's (1969) Temporal Perceptual Resolution factor, in that variable 39 (CFF) is common to all of these studies. Although variable 41 only had a loading of .28, it is consistent with the tentative interpretation of this factor. It was also found to load highly on Aftanas and Royce's (1969) factor.

This factor correlated with damage to the parietal and temporal regions of the right hemisphere. Impaired performance on the two measures loading on this factor has been demonstrated as a result of damage to these areas of the brain (Reitan, 1958; Chandler, *et al.*, 1966). The interpretation of this factor, which has two unrelated measures (i.e., C.F.F., traditionally a sensory-visual variable and finger tapping, being a motor variable), was made on the assumption that the brain areas damaged were involved in some higher integrative processes of afferent and efferent neural activity. Consistent with this interpretation is the finding that finger tapping for the right hand also had a high loading on this factor, even though ipsilateral involvement of the right side would not be expected to load as high as it did from previous findings (Reitan, 1964; Williams, 1970).

Factor VIII. Five variables have loadings of .30 or higher on this factor. They are:

48	Face-Hand (omissions)	–.67
29	Finger Localization (non-preferred)	–.55
50	Age	–.35
4	Trail Making B	–.35
16	Symbol-Gestalt (errors)	–.35

This factor is interpreted as *spatial orientation.* It is characterized by the ability to maintain spatial relations among objects (e.g., brain damage cases become disoriented). Variables 4 and 16 would appear to be related to visuo-motor activity, and variables 29 and 48 are usually subsumed under disorders of body schema. The latter two variables are clearly related to spatial localization of body parts, whereas variables 4 and 16 involve localization of figures in extra-personal space. Since variables 29 and 48 have the higher loadings on this factor, they suggest an interpretation related to somatognosia. However, the findings and conclusions of Benton (1961), Fogel (1962), Ettlinger (1963), Orgass and Poeck (1968), and Poeck and Orgass (1969) that finger agnosia and left-right disorientation cannot be considered as unitary disorders support the above interpretation, which subsumes a wider range of symptoms (Frederiks, 1969, and Poeck, 1969).

The loading of age on Factor VIII is consistent with studies showing that these variables interact with age level (Benton, 1959; Green and Fink, 1954; Parsons, Maslow, Morris, & Denny, 1964). However, several studies (Fitzhugh & Fitzhugh, 1964; Fitzhugh, Fitzhugh & Reitan, 1964; Reed and Reitan, 1963a and 1963b; and Reitan, 1967) have shown that there are differential age effects, depending on whether the tests could be solved using past stored information as contrasted to *S*s primarily utilizing their immediate adaptive abilities or intelligence.

Poor spatial orientation correlated with damage to the parietal and frontal areas of the right hemisphere and better orientation occurs in these subjects with damage to the frontal and temporal regions of the left hemisphere. This is compatible with the multitude of studies relating visual-spatial disturbances to the parietal region of the brain (Benton, 1959, 1961, 1962; Fogel, 1962; Hécaen, 1969; Heimburger, et al., 1957, 1964; Jewesbury, 1969; Poeck & Orgass, 1966, 1969; Poeck, 1969).

Factor IX. Three variables have loadings of .30 or higher on this factor. They are:

40	Binaural Beats	–.52
47	Apparent Motion	–.50
20	Halstead Category Test—II	–.35

This factor is tentatively interpreted as *figure-ground identification.* It is hypothesized that the basic perceptual process of selecting a figure from a stimulus complex is the main determinant involved in the solution of the variables loading on this factor.

As in Factor VII, the variables loading on this factor involve two different sensory modalities. The variables are similar in that the solution for two of the tests is contingent upon the *S*'s perception of a figure-ground relationship.

Poor figure-ground identification is associated with damage to the left occipital and right frontal regions, while better identification is associated with damage to the temporal regions of both hemispheres. The visual components of variables 20 and 27 is consistent with the correlation of this factor with occipital damage in contrast to binaural beats. The correlation of right frontal damage may be related to attentional components and eye scanning involved in these tasks (Luria, 1969, and Pribram, 1971).

Factors XI, XII, and XIII. The remaining factors are considered to be uninterpretable. Thus, we summarize herewith (and without comment) the high loadings for these three factors: Factor XI: CFF—Ascending (.66), and Minutes Tested (.37); and Halstead Category III (–.33); Factor XII: Symbol Gestalt—Total Weighted Score (.49), and Improvement (.49), Age (.46): Factor XIII: Handedness (.54), Age (–.43), Sex (–.42), and Retinal Rivalry (.37).

The Second-Order Factor Analysis

A second-order alpha factor analysis was performed on the correlation matrix of the primary axes obtained from the promax 2 solution (see Table 7), using squared multiple correlations as

initial estimates of the communalities. Five factors had eigenvalues greater than one. Since the primary factors were approximately orthogonal, the communalities and eigenvalues for the second-order factors are quite small. The second-order factors were transformed to simple structure with respect to the first-order factors via promax 2 (Cattell-White procedure). Thus, second-order factor scores were calculated for these factors via the regression method, and subsequently correlated with neurological sites (see Table 8).

The primary factor pattern for the second-order factors in terms of the first-order factors is given in Table 9 and the loadings in terms of the original variables are given in Table 10. To aid interpretation, the second-order factors were reflected so that a *high factor score is indicative of better performance on the tests.*

The first factor is interpreted as *perceptual integration,* a general, cross modality, ability to process and synthesize sensory inputs. Eight of the variables (1, 3, 5, 6, 7, 8, 10 and 12) and first-order factors I (perceptual organization, .47), III (perceptual-motor speed, .40) and VII (temporal resolution, .54) have high loadings on this factor. The nature of the variables and first-order factors identifying this factor suggests an interpretation reflecting what Frederiks (1969) has called "disorders of perceptual recognition." Low scores on this first second-order factor are associated with damage to the frontal, temporal, and parietal regions of the right

Table 9
Primary Factor Pattern of Second-Order Factors

First-Order Factors	I	II	III	IV	V
1 Perceptual Organization	47	14	10	–14	02
2 Verbal Comprehension	30	51	–13	09	–06
3 Perceptual-Motor Speed	40	07	15	–04	–07
4 Memory	08	48	03	–36	09
5 Pattern Recognition	30	29	12	01	26
6 Abstraction I	30	02	29	01	–02
7 Perceptual Resolution	54	06	–10	05	20
8 Spatial Orientation	25	05	37	11	00
9 Figure-ground Identification	–01	–08	50	–11	03
10 Abstraction II	–04	03	–02	09	45
11 Not Interpreted	04	02	01	52	15
12 Not Interpreted	–11	29	28	04	24
13 Not Interpreted	13	01	32	–20	21

Table 10
Loadings of Variables on Second-Order Factors

Neuropsychological Variables	I	II	III	IV	V
1	–.15	–.42	.03	.10	.01
2	–.32	–.44	–.09	.04	.01
3	–.31	–.27	–.15	–.18	.05
4	–.43	–.21	–.08	–.09	–.00
5	.42	.24	.04	.13	–.06
6	.29	.41	–.05	.06	–.02
7	.14	.49	–.14	.00	–.04
8	.45	.26	.17	.14	–.11
9	.38	.24	.20	.11	–.06
10	–.33	–.21	–.18	.01	.17
11	–.33	–.29	–.19	–.03	.22
12	–.33	–.27	–.12	.01	.18
13	.43	.11	–.08	.07	.18
14	–.48	–.05	.02	–.08	.02
15	.44	.26	.08	.15	.02
16	–.35	–.25	–.13	.17	.03
17	.02	.18	.10	–.07	.12
18	.31	.36	.22	–.02	.08
19	–.09	–.36	–.10	–.16	.10
20	–.23	–.12	–.32	–.05	–.16
21	–.12	–.01	–.21	–.07	.15
22	–.30	–.20	.01	–.07	.22
23	–.33	–.10	–.19	–.07	.09
24	–.37	–.13	–.16	–.04	.10
25	–.36	–.08	–.23	–.12	.16
26	–.20	–.35	–.26	–.16	.06
27	–.08	–.48	.12	–.15	.01
28	–.27	–.26	–.25	–.20	.02
29	–.31	–.12	–.34	–.03	.17
30	–.29	–.18	–.08	.05	.06
31	.16	.22	–.06	–.11	–.20
32	–.43	–.04	–.16	.02	–.07
33	–.41	–.04	–.29	.07	.02
34	–.43	–.01	–.34	–.02	–.01
35	.25	.06	.21	–.04	–.05
36	.29	.15	.21	–.00	–.09
37	–.31	–.18	–.10	–.08	–.02
38	.02	–.13	.01	.29	.02
39	.15	.06	.08	.02	.27
40	.10	.06	.32	.08	–.01
41	.29	.09	.11	–.05	.08
42	.34	.36	–.06	.07	.08
43	.44	.13	.08	.21	.03
44	.42	–.02	.24	–.04	–.10
45	.40	–.03	.26	.04	–.07
46	.45	.06	.27	.05	–.03
47	–.05	.10	–.16	–.12	.10
48	–.18	–.01	–.18	.01	.12
49	–.17	–.18	–.34	–.16	–.06
50	–.39	.04	–.00	.08	.05
51	–.09	–.06	–.04	.00	–.21
52	–.38	–.07	.02	.12	.01
53	–.02	–.05	.13	–.02	.08
54	.20	.26	–.16	–.13	–.01

hemisphere. Better perceptual integration appeared in those subjects with damage to the occipital regions of the right hemisphere and temporal and subcortical regions of the left hemisphere.

The second factor is interpreted as *verbal memory*, a general ability to retrieve verbal associations from either long or short-term storage. It is identified by variables 1, 2, 6, 7, 18, 19, 26, 27, and 42, and first-order factors II (verbal comprehension, .51) and IV (memory, .48). Poor verbal memory is associated with damage in the temporal and subcortical regions of the left hemisphere while higher verbal ability occurs in those subjects with damage to the temporal and parietal regions of the right hemisphere.

The third second-order factor is interpreted as *visualization*, a general ability to imagine objects in space. It includes both static and dynamic structures, such as perceiving critical elements or gestalts and their restructurings, and the movements of objects in space. It is identified by variables 20, 29, 33, 34, 40, and 49, and factors VIII (spatial orientation, .37) and IX (figure-ground identification, .50). Poor performance on visualization is associated with damage to the frontal and subcortical regions of the right hemisphere and with the occipital regions of the left hemisphere. Visualization performance improves if damage occurs in the frontal and temporal regions of the left hemisphere.

The second-order analysis suggests that the 13 dimensions identified in the first-order analysis may reflect dysfunction of second-order cerebral processes in addition to reflecting unitary functional processes at the first-order. It is clear from recent theoretical and empirical developments (e.g., see Royce, 1973a) that human cognition is hierarchically organized. And the present research has uncovered three of these higher-order, integrative processes of a perceptual-conceptual nature. We'll explore the theoretical implications of these findings in the Discussion section below.

Discussion

The primary value of this investigation lies in the identification of cognitive dimensions which are correlated with human brain damage. Of the ten interpretable first-order factors, six are perceptual in nature and four are of a more conceptual nature. The perceptual factors include: perceptual organization, perceptual-motor speed, pattern recognition, temporal resolution, spatial orientation, and figure-ground identification. The conceptual factors include verbal comprehension, memory, and Halstead abstraction I and II.

Although most of these factors have been identified before, they have rarely been identified in the context of human brain damage. For example, spatial orientation, memory, and verbal comprehension are three of the original Primary Mental Abilities. Perceptual and motor speed factors have been repeatedly reported in the factor literature, but pattern recognition, temporal resolution, and figure-ground identification have rarely been identified previously. The Halstead Abstraction I and II factors, on the other hand, have been identified in previous brain damage batteries, but their factorial significance is not at all clear. The present study adds to the growing evidence that several dimensions are buried in the Halstead abstraction tests, and that two of them look very much like Guilford's cognition of figural classes (CFC) and cognition of figural transformation (CFT).

As part of a general theory of individual differences (Royce, 1973b, Royce, Kearsley, and Buss, Note 7) the senior author has developed a taxonomy of cognitive factors. The 40 or so factors of the resulting hierarchical structure include five of the ten first-order factors identified in the present study. These are perceptual organization, verbal comprehension, perceptual-motor speed, memory, and spatial orientation. In terms of the Royce model the first-order verbal comprehension factor of this study would be subsumed under a second-order verbal factor, the first-order memory factor would be subsumed under a second-order memory factor, and the first-order spatial relations factor would be subsumed under a more general second-order factor labeled visualization. It is highly probable that the perceptual-motor speed factor of this study is some conglomerate of such second-order factors as motor precision and motor tempo.

Since empirical investigation of higher order dimensions is not extensive, and theoretical synthesis of these findings is in its early stages, current insights concerning what is going on at these levels is necessarily speculative. However, it seems reasonable to suggest that the three second-order factors of the present study are either related to or the equivalents of higher order factors in the Royce model. Thus, we hypothesize that the Royce second-order visualization factor is the same as the visualization factor of this study, that the second-order perceptual integration factor of this study is probably the general third-order perceptual factor in the Royce model,

and that the verbal memory factor of this study appears to be either a new factor or the verbal portion of a more general second-order memory factor (which includes both verbal and non-verbal memory).

A major current dilemma in the cognitive domain is that the cumulative empirical evidence is sufficient to indicate that there are, indeed, higher order dimensions, but there is confusion concerning the strata allocation of these dimensions. While there is at least a body of empirical findings available at the second-order, we are badly in need of research which will extend our understanding of the higher strata of this hierarchical structure (e.g., see Royce, 1966, 1973a, and 1973b for a summary up to the second stratum). The Royce model includes three cognitive sub-systems designated as perceiving, conceptualizing, and symbolizing. Thus, of the ten first-order factors of this study, six of them are subsumed under the third-order construct of perceiving, and the other four are part of the conceptualizing sub-system. And two of the three second-order factors of this study, visualization and perceptual integration, are part of the perceptual sub-system, and verbal memory is subsumed under conceptualizing. Thus, in terms of the Royce model, eight of the thirteen interpreted factors of this investigation are perceptual in nature, five are conceptual, and none is of a symbolizing (the third sub-system) nature. Since this investigation was focused on the perceptual sub-system, it seems clear that if future efforts are focused on the other two sub-systems, there will be a significant pay-off regarding factor-brain correlates.

We will now consider the neural basis for factors of cognition. The factor analytic approach focuses on identifying behavioral functional unities. If we carry this concept over into brain function, it implies the existence of neural functional unities—this means the organization of subsets of neural systems as the counterparts of psychological dimensions. When a particular neural correlate of a psychological process occurs entirely *within* a known anatomical system, we speak of localization of function. To the extent a particular correlate of a psychological process occurs *across anatomical units* we regard such functioning as relatively non-localized. The most convincing evidence to date for localization of cognitive factors comes from Halstead (1947)—in particular, his finding that his memory factor is more dependent upon functioning of the left hemisphere than the right hemisphere and that his abstraction factor is primarily localized in the frontal lobes. Our investigation indicates that about half the interpretable factors are relatively localized (i.e., confined to one or two lobes of one hemisphere), and that the other half are relatively diffuse (i.e., multilobed, combined with laterality or bilaterality). A summary of the major (i.e., the highest correlations for a specified brain site) neural correlates for each factor can be found in Table 11.

Table 11
Factors Classified by Major Neural Correlates[a]

	Laterality of Cerebral Function	
Lobes	Left Hemisphere	Right Hemisphere
Frontal	Verbal Comprehension Verbal Memory	Perceptual-Motor Speed Figure Ground Halstead Abstraction I and II Spatial Orientation Perceptual Integration Visualization
Parietal	Perceptual Organization Pattern Recognition	Perceptual-Motor Speed Halstead Abstraction I and II Temporal Resolution Spatial Orientation Perceptual Integration
Temporal	Verbal Comprehension Memory Verbal Memory	Perceptual Organization Temporal Resolution Pattern Recognition Halstead Abstraction I Perceptual Integration
Occipital	Figure Ground Pattern Recognition Halstead Abstraction I	Halstead Abstraction I
	Memory Verbal Memory	Perceptual-Motor Speed Halstead Abstraction I Temporal Resolution Perceptual Integration Visualization

[a]The following subcortical neural correlates were also observed:
(a) memory - left temporal and frontal lobes
(b) verbal memory - left hemisphere
(c) abstraction I - generalized right hemisphere
(d) visualization - right hemisphere

According to this table the right hemisphere factors of perceptual-motor speed, temporal resolution, and spatial orientation, and the left hemisphere factors of verbal comprehension, memory, and verbal memory are relatively localized in terms of cortical representation. The right hemisphere factors are localized primarily in the frontal and parietal lobes, and the left hemisphere factors are localized primarily in the fronto-temporal areas. Another factor, perceptual organization is represented bilaterally, but not symmetrically (i.e., in different lobes).

As might be expected, the second-order factors tend to be diffusely distributed anatomically. Perceptual integration is the most obvious case in point, since it is represented in all but the occipital region of the right hemisphere. Visualization is primarily a frontal, right hemisphere factor, but there are multi-lobe and bilateral secondary implications because of its first-order factor identifications. The most localized of the second-order factors is verbal memory, which is associated with damage to the cortical and subcortical regions of the frontal and temporal lobes of the left hemisphere.

We view the diffuse cortical representation of three of the first-order factors with special interest because of the possible implications of such findings for deciding on the strata allocation of factors. The factors in question are the Halstead abstraction factors and pattern recognition, distributed bilaterally but asymmetrically, and the Halstead abstraction factors represented throughout the right hemisphere. Biological reasoning suggests that a high degree of cross anatomical representation of a psychological function would be characteristic of a higher order factor. This is offered on the grounds that integrative (i.e., higher order) factors involve interactions between subsets of neural cells which cut across functionally significant anatomical units. Thus, although they were identified at the first-order in this study, it is possible that pattern recognition and the two abstraction factors are actually higher order constructs. This is put forth as an hypothesis which requires further empirical investigation at the psychological level (i.e., spelling out the behavioral boundary conditions of these factors) as well as at the neurological level.

What is most clearly lateralized in this investigation? According to Table 11, memory, verbal comprehension, and verbal memory are left hemisphere functions, and about five perceptual factors (the second-order factors of perceptual integration and visualization, and the three first-order factors of spatial orientation, perceptual-motor speed and temporal resolution) and the two abstraction factors are right hemisphere functions. These factor-brain correlate findings are consistent with the general body of (non-factorial) neuropsychological knowledge. The most obvious examples of convergence of findings are the localization of the verbal comprehension factor in the fronto-temporal regions of the left hemisphere and the localization of the spatial orientation factor in the fronto-parietal regions of the right hemisphere. (Diamond, 1972).

The discrepancy between our findings and the earlier reports of Halstead on the abstraction factor should be alluded to by way of pointing up how coordinated, cumulative efforts can advance our understanding of factor-brain correlates. Our investigation provides two correctives to the original Halstead reports. First, that at least two factors are at work in what is actually an "abstraction test battery." Thus, we agree with the Haynes & Sells (1963) conclusion that this test is multidimensional, and, because of its demonstrated value to the human brain damage literature, factor studies are necessary in order to clarify the nature of the subtests as they relate to human brain function. Secondly, our findings indicate that decrements in factor scores on abstraction factors are attributable to damage in the parietal, temporal, and occipital lobes as well as the frontal lobes. Thus, replications with more adequate (e.g., invariant factors and more comprehensive test batteries) factor identification is required on the psychometric side, and replication with more adequate lesion controls is required on the neurological side.

Our findings also bring out several shortcomings and difficulties of human brain damage research. Perhaps the most provocative of these difficulties is the fact that, in specified cases, brain damage resulted in an increment in factor performance rather than a decrement. How can this be explained? Needless to say, procedures do not exist at present for providing an adequate answer. However, we can offer some ideas for further elaboration and investigation. Assuming that our findings are not artifactual on either statistical or other grounds, the best available explanation is that of "compensatory functioning." In terms of the factor model, this simply means that a given situation is dealt with via whatever factor components are available to the organism. For example, if a cognitive task ordinarily involves three factors and no others, but all the subjects in question have lost the utilization of the same one of those three components because of localized brain damage, then those subjects will simply do the best they can on that task on the basis of the remaining components. In the most obvious case of compensatory functioning, if we assume the same performance level on a task after brain damage as before, then it follows that, in the case just cited, it would be attributable to a higher level of functioning on one or both of the two remaining factors. For example, compensatory functioning can account for the ubiquitous finding (e.g., the Greystone project) that extensive brain damage does not necessarily result in a loss of I.Q. Based on the logic of the factor model, two possibilities follow. One is that the damage is randomly distributed over all the intellectual components at a below threshold (i.e., it does not become manifest) level. The other explanation is that the damage is non-randomly distributed over a specifiable number of components and that, since the average of all the components (i.e., the I.Q.) is the same, there must be an increment in the performance level of one or more of the non-decremented components.

Another problem has to do with the small magnitudes of the brain site correlations. Although there are exceptions, studies which attempt to link the psychological and physiological domains of investigation have a long history of low correlations (e.g., see Royce, 1950 and 1966) in spite of the availability of highly controlled laboratory settings involving animal subjects. It is unlikely, therefore, that the usual cry of unreliability will offer a complete account for this state of affairs. It is more likely that it is a reflection of the intrinsic nature of the relationships between biological and behavioral events. However, in the present study, we are subject to the usual limitations of clinical investigations. Thus, attenuation of correlation coefficients would be expected from our use of a mixed population of patients in terms of etiology of damage, acuteness vs. chronicity, and post-operative recovery time, as well as such factors as lowered accuracy in the localization and extent of lesions in the clinical setting.

A more serious source of confounding arises from the inclusion of patients with dysfunction in more than one area of the brain, as in the case of cerebrovascular disorders or multiple focal lesions. Thus, the contribution of focal lesions to variance related to specific variables loading on the various factors would be attenuated by subjects with dysfunction in more than one area of the brain. In addition to the above confounding, it is probably incorrect to assume simple additive effects of multiple focal lesions, as it appears that unique neuropsychological profiles result in such cases (Reitan, 1972, Note 8). Finally, one other source of attenuation arises from the exclusion of normals (the correlations were calculated on a population of restricted range consisting of only brain damaged subjects). Future reports (Royce, Yeudall, & Wardell, Note 5, and

Yeudall, Royce, & Bock, Note 6) will include analyses involving both normals and brain damage cases.

The fact that most of the factors tended to be correlated with damage in more than one area of the brain suggests another possible major source affecting the obtained correlations. The probability is extremely low that any random brain damage population would have lesions in the appropriate areas in regard to any one factor. For example, Factor I correlated with the frontal and temporal areas of the right hemisphere, and the parietal area of the left hemisphere. In this case it is assumed that partial dysfunction of one or even two of these areas (depending upon extent) could be compensated to some degree by the remaining intact areas of the brain which are normally involved in the solution of the tasks loading on this type of factor. If, as in Factor I, there can be varying degrees of compensation of dysfunction by remaining intact relevant areas, then one would expect this to attenuate systematically the correlations between a factor and its related neurological sites.

While we must admit that the neural correlate findings only provide clues as to which areas are involved for a given factor, we are encouraged by the overall pattern of our findings, including the fact that they are not inconsistent with the extant non-factorial literature.

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