A FACTOR ANALYSIS OF BRAIN DAMAGE TESTS ADMINISTERED TO NORMAL SUBJECTS WITH FACTOR SCORE COMPARISONS ACROSS AGES[1, 2]

M. S. AFTANAS
University of Manitoba

and

J. R. ROYCE
University of Alberta

ABSTRACT

This study investigated the factorial composition of brain damage tests selected on the basis of a comprehensive review of the test literature. The tests were administered to 100 normal persons between the ages of 16 and 70.

Two analyses were performed. The first analysis concerned the determination of the factorial composition of the brain damage tests selected. The results suggested that although the dimensionality of the brain damage test battery is relatively complex, the majority of the tests discriminate on the basis of a few dimensions, at least for normal persons.

The second analysis involved the determination of factor scores for each individual on the twelve factors extracted in the 16-70 age group analysis. An analysis of the factor scores as a function of age indicated a significant difference for only two of the factors. This finding was discussed in terms of the possibility that certain of the tests would be psychometrically more efficient in differential diagnosis of brain damage in the older person.

Over the last thirty years a vast number of tests have been constructed for the purpose of identifying the individual with cerebral dysfunction and, in some cases, for isolating the specific locus of the lesion. One of the most successful batteries of such tests has been constructed by Halstead (1947) and used in a modified form with considerable success by Reitan (1959). The primary interest of the Halstead-Reitan battery, as used by Reitan, is to measure as many individual input-mediation-output dimensions as possible so that loss of a specific function might suggest a specific localized lesion. The emphasis in this approach is to provide as complete a description as possible of the individual's level of functioning in terms of a large number of dimensions.

The success of such an approach depends to some extent on

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3. This research was conducted while the first author held a postgraduate scholarship from the National Research Council of Canada.

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the purity of the measure being used to tap a particular dimension, the degree to which the several tests tap different dimenions, and the degree to which the tests are age independent. A measure which is dependent upon several abilities for successful completion would not be expected to indicate specific lesions because poor performance may be a result of deterioration in any one or all of the abilities or dimensions being measured by the test. On the basis of this consideration it would be expected that rather gross measures, such as general intelligence tests, would be of limited value in the identification of specific lesions (Haynes and Sells, 1963). Similarly, a test battery which in fact contains tests that overlap and measure only a limited number of input-mediation-output dimensions would also have limited value since much of the information gained would be redundant. It would also seem reasonable that a test which does not discriminate between age related deficits and specific lesions would not have general validity since low scores may be a function of either a specific lesion or the aging process. Schludermann, Brown and Halstead (1965) and Schludermann (1966) have found that certain of the tests in the Halstead battery were not differentially sensitive to age related deficits and frontal lobe damage. Schludermann (1966) also found a consistent positive relationship between age and the Halstead impairment index. These results suggest that psychometric evaluation of older persons suspected of brain damage would result in a large number of false positives. In terms of the above considerations, and in view of the desirability of having measures which would allow the identification of specific lesions, it would seem that a study of the dimensionality of the more valid and reliable brain damage tests and determination of differences in scores as a function of age is long overdue.

Several factor-analytic studies of brain damage tests have been reported, but these have been limited in terms of the types of tests included in the battery. Halstead's original work in this area (Halstead, 1947) involved a factor analysis of thirteen measures which resulted in the extraction of four factors. One of these factors, however, was a doublet which makes interpretation difficult, if not impossible. The fact that only four factors were extracted suggests that there is duplication in the tests and perhaps a dearth of marker variables which could be used to identify other sources of variance. Coppinger, Bortner and Saucer (1963) report a study in which 42 variables were factor analyzed after being administered to 88 subjects. Of the nine factors extracted seven ed to tap a particular dimension, tests tap different dimenions, are age independent. A measure bilities for successful completion e specific lesions because poor eterioration in any one or all of measured by the test. On the d be expected that rather gross ence tests, would be of limited cific lesions (Haynes and Sells, hich in fact contains tests that ed number of input-mediation- limited value since much of the ndant. It would also seem rea- t discriminate between age re- vould not have general validity of either a specific lesion or the wn and Halstead (1965) and that certain of the tests in the ntially sensitive to age related chludermann (1966) also found between age and the Halstead ggest that psychometric evalua- brain damage would result in a terms of the above considera- lity of having measures which specific lesions, it would seem of the more valid and reliable ion of differences in scores as

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consisted almost entirely of sub-tests from a single test. This finding, coupled with the fact that abnormal groups were incorporated in the sample, makes interpretation of the factors and generalization from the study difficult. In two other factor-analytic studies, Jones and Wepman (1961), and Schuell, Jenkins and Carroll (1962) report on the dimensionality of language deficit. The tests incorporated in these studies were aimed primarily at determining the nature of language performance in brain injured patients. For a more complete review of the factor-brain correlate literature, including the issue of factorial invariance (a problem which is of particular importance in the domain of biopsychology), see Royce (1966).

The present study is related to a broader research program (Royce, 1968) whose goals are to: (1) identify neurologically relevant factors in the domain of cognition; (2) determine the relationship between cognitive factors and brain loci; (3) identify invariant factors across brain damaged and non-brain damaged populations; and (4) provide an impairment index for predicting the extent and locus of brain damage. The present study is focused on identifying those dimensions being measured by the more reliable and valid brain damage tests presently available. A heterogeneous, normal (or non-brain damaged) group is being tested so that a maximum number of sources of variance on the tests will become evident in the analysis. It seems reasonable to assume that, for some tests at least, individuals with deficits would perform at or near the "floor" of these tests so that minimum variability would be evident. An analysis of a sample of normal individuals should also provide a basis for comparison when the same tests are administered to selected samples of brain damaged subjects.

The present study will also investigate the factorial complexity of these tests of brain damage. Ideally, each individual test in a battery of tests which is to be used for identifying specific brain lesions should measure a single dimension. A test which is factorially complex would not allow for the identification of a specific lesion since a low score may result from a deficit in any one or more of the dimensions being measured by the tests.

Finally, the sample selected for study will range in age from 16 to 70 so that factor scores for each factor can be plotted as a function of age. The determination of age related and non-age related tests and factors can serve two functions. It will allow (a) the selection of tests most sensitive to some types of brain damage in the older groups and (b) the determination of functions which are related to both age and brain damage. It should be made clear that the results should suggest those tests which are psychometrically most efficient for the older person rather than indicate age changes. It is realized that a modified procedure such as has been presented by Schaie (1965) would be required to demonstrate the latter.

Method

Subjects

The sample of *S*s selected for testing consisted of 100 persons between the ages of 16 and 70 years of age. Fifty of these *S*s were between 16 and 35 years and another fifty were between 36 and 70 years of age. An attempt was made to keep the distribution of *S*s within these age groups constant across specific age ranges. In the 16-35 year group the range was five years while in the 36-70 group the range was increased because of the extensive period under consideration. Table 1 presents the distribution of *S*s within the various age groups. The only other criterion used in the selection of subjects was freedom from any known injury which might have resulted in brain damage.

Table 1
Distribution of subjects within the different age groups

Age Group	16-20	21-25	26-30	31-35	36-45	46-55	56-65	66+
Number	16	11	13	10	15	14	12	9

Tests

The tests used in this study were compiled on the basis of an exhaustive search through the literature for tests which were reported to discriminate between brain lesion groups and normals. The initial search and selection of these tests was made under the direction of the second author. A review of approximately 300 titles resulted in an initial list of 75 tests. Twenty-nine of these tests were chosen for inclusion in the battery 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 (Royce & Carran, 1964). Four of these tests were not included in this study because they were unavailable or because preliminary testing indicated a complete lack of variability in a normal sample. The inclusion of twenty-five

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tests resulted in a total of thirty-four variables since some tests, such as Halstead's Tactual Performance Test (Halstead, 1947) involved more than one measure. The measures and the primary validity sources are given in Table 2. Age was included as variable thirty-five for purposes of the factor analysis.

Table 2
The Complete Set of Variables in the Order in which they Appear in all Analyses
Validity Study for Each Test

TEST	PRIMARY REFERENCE
1. Coloured Progressive Matrices	Dils (1960)
2. Proverbs	Elmore & Gorham (1957)
3. Retinal Rivalry	Sappenfield & Ripke (1961)
4. Modified Word Learning	Walton & Black (1957)
5. Apparent Motion	Saucer & Deabler (1956)
6. Organic Integrity	Tien (1960)
7. Binaural Beats	Price *et al.* (1958)
8. Grassi Accuracy	Grassi (1953)
9. Grassi Time Credits	Grassi (1953)
10. Symbol Gestalt	Stein (1962)
11. C.F.F. Mean	Halstead (1947)
12. C.F.F. Deviation	Halstead (1947)
13. Porteus Mazes(s)	Porteus (1959)
14. Memory for Designs	Graham & Kendall (1946)
15. Halstead Rhythm	Halstead (1947)
16. Tactual Performance Latency	Halstead (1947)
17. Tactual Performance Memory	Halstead (1947)
18. Tactual Performance Localization	Halstead (1947)
19. Trail Making Latency	Reitan (1955)
20. Hooper Visual Organization	Hooper (1952)
21. Halstead Speech Sounds	Halstead (1947)
22. Halstead Category	Halstead (1947)
23. Minnesota Percepto-Diagnostic	Fuller & Laird (1963)
24. Grayson Perceptualization	Grayson (1954)
25. Sound Localization Separation	Shankweiler (1961)
26. Sound Localization—Localization	Shankweiler (1961)
27. Purdue Pegboard Total	Costa *et al.* (1963)
28. Purdue Pegboard Assemblies	Costa *et al.* (1963)
29. Kahn Test-Symbolization	Kahn (1951)
30. Kahn Test-Recall	Kahn (1951)
31. Muller-Lyer Error	Jenkin & West (1959)
32. Muller-Lyer Difference	Jenkin & West (1959)
33. Reaction Time Simple	Benton & Blackburn (1959)
34. Reaction Time Choice	Benton & Blackburn (1959)
35. Age	

Procedure and Analysis

The placement of the tests in the battery was directed by several considerations, the primary one being to intersperse the tasks so as to maintain the interest and motivation of the *S*. The shorter tasks were alternated with longer ones, and tests which seemed to require certain abilities were placed so that tests of other abilities would intervene. This consideration was felt to be of greater importance for those tests requiring continued perceptual or motor components because of the possibility of satiation effects. The simpler tests, which were felt not to require a high degree of ability, were placed at the start of the battery in an attempt to alleviate apprehension concerning the test situation.

Testing was conducted with individual *Ss* in multiple test sessions. The length of the test session varied depending on the age of the *S* and the amount of time he had allotted for the session. If an entire morning were involved then a break was introduced. Testing was discontinued if *S* began to feel tired.

The data for the 100 persons on the thirty-five variables were first correlated and then submitted to an Alpha Factor Analysis (Kaiser and Caffrey, 1965). The initial estimate of the communality entry was the squared multiple correlation of each variable with every other in the matrix. The solution was iterated until the communalities converged with a .01 criterion. The criterion used for determining the number of factors to retain for rotation was that outlined by Kaiser and Caffrey (1965).

The method and criteria used for oblique rotation of the Alpha factor matrix were those outlined by Hendrickson and White (1964). The first step was to use the Varimax analytic criterion (Kaiser, 1958) to achieve orthogonal simple structure. The Promax method was then used to achieve oblique simple structure. This method begins with an orthogonal solution, such as Varimax, and powers the elements of this matrix so as to maximize the differences between the high and low loadings. The method then involves the determination of a least squares fit of the powered matrix to the orthogonal matrix of factor loadings. The Procrustes equation outlined by Hurley and Cattell (1962) is used for this purpose. One problem in using the Promax method involved the selection of a value for k, the power to which the elements of the Varimax solution were taken. After several values of k, ranging from two to six, were attempted, the power two and four solutions were selected and plotted in two dimensional sections. Inspection of these sections for the two different solutions indicated a better simple structure for the power two solution, and this was selected for interpretation.[4]

4. Royce is conducting an empirical study of the adequacy of simple structure fit using several analytical solutions and graphic rotation. One comparison to date (involving mouse emotionality data) between the Promax rotation and blind graphic rotations from the Varimax solutions reveals essentially identical results. It is anticipated that the data from the present study will eventually be graphically rotated and similarly compared with the Promax solution herein reported.

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The final analysis undertaken was the determination of an n × r factor score matrix based on the factor solution for the entire age range, 16-70. The program used for this purpose was based on Kaiser's (Kaiser, 1962) modification for the determination of factor score estimates. The factor matrix used for this analysis was the Promax rotated matrix with a *k* value of two. This particular matrix was selected for two related reasons. It was felt to be desirable to select that factor matrix for the 16-70 age group upon which the interpretation of the factors had been based. This selection would allow a more meaningful discussion of possible changes in factor scores as a function of age. The related reason is based on the degree of obliquity observed between the factors after the Promax rotation. Use of the Promax rotation would have been obviated with a high degree of obliquity because factor changes observed for one factor would not necessarily have been independent of a correlated factor. In view of only a slight degree of relationship, as indicated by the cosine matrix, however, the increase in meaningfulness of discussion was felt to more than compensate for the possible lack of independence. Finally, the factor scores obtained for each factor across age groups was submitted to an analysis of variance to determine whether any of the changes were significant.

Results and Interpretation of Factors

The basic analyses for the total group are outlined in Tables 3, 4, 5 and 6. Convergence for the Alpha analysis was attained after thirteen interations and twelve factors were retained for rotation. For purposes of interpretation variables having loadings greater than ± .30 were considered. Maximum weight for the interpretation was, however, assigned to variables having substantially higher loadings than this minimum.

FACTOR I

The variables with loadings above .30 on Factor I are:

18.	Tactual Performance—Localization	+.657
17.	Tactual Performance—Memory	+.602
14.	Memory-for-Designs	+.597
20.	Hooper Visual Organization	+.549
16.	Tactual Performance—Latency	−.545
1.	Coloured Progressive Matrices	+.498
13.	Porteus Maze	+.449
22.	Halstead Category	+.443

Table 3
Product-Moment Correlations for the Thirty-Five Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1																		
2	.556																	
3	.175	.117																
4	.095	.091	.313															
5	-.077	-.005	.152	.059														
6	.052	.002	.319	.221	.057													
7	.139	.042	.174	.018	.000	-.001												
8	.224	.255	.036	.115	-.043	.048	-.014											
9	.273	.272	.124	.276	.051	.029	.066	.233										
10	.253	.156	.242	.058	-.114	.162	-.068	.239	.277									
11	.007	.097	.306	.267	.049	.191	.144	.240	.180	.127								
12	-.023	-.120	.090	.064	-.039	.121	-.012	.028	.051	.157	.006							
13	.507	.264	.030	-.034	-.040	.008	.081	.056	.178	.177	-.073	.010						
14	.506	.278	.341	.141	-.014	.252	.100	.210	.201	.380	.159	.162	.464					
15	.226	.310	.245	.143	-.103	-.039	.178	.013	.217	.176	.120	.076	.121	.172				
16	-.284	-.136	-.259	-.158	.025	-.262	.027	-.160	-.129	-.316	-.227	-.096	-.348	-.585	-.204			
17	.367	.309	.125	.292	-.086	.209	.011	.159	.221	.342	.120	-.089	.208	.429	.171	-.418		
18	.395	.339	.243	.244	-.121	.209	.145	.242	.234	.341	.186	.049	.267	.498	.212	-.462	.676	
19	-.301	-.196	-.314	-.111	-.041	-.177	.040	-.184	-.289	-.431	-.113	-.131	-.432	-.524	-.371	.502	-.297	-.374
20	.399	.318	.184	.131	.098	.163	.145	.282	.231	.239	.108	-.032	.331	.473	.026	-.413	.335	.444
21	.162	.301	.044	.152	-.025	.086	-.020	.180	.274	.050	-.052	-.026	-.025	.110	.219	-.014	.082	.126
22	.468	.303	.160	.199	-.006	.238	.101	.207	.429	.320	.022	.042	.412	.451	.146	-.345	.329	.414
23	-.080	-.005	-.303	-.121	-.156	-.107	.124	-.049	-.132	.010	-.159	-.062	-.193	-.159	-.071	.283	-.184	-.243
24	.397	.313	.291	.025	.082	.077	.052	.062	.233	.358	.058	.022	.270	.447	.207	-.401	.281	.317
25	-.221	-.010	.100	.035	-.125	-.016	-.158	.000	-.076	.145	.119	.044	-.170	-.079	-.009	-.070	-.001	-.001
26	.057	.026	-.154	-.190	-.028	-.095	-.029	-.014	-.243	.020	-.091	.112	.044	-.171	-.075	.134	.028	-.162
27	.162	.022	.311	.007	.091	.050	-.129	-.061	.160	.336	.033	.121	.246	.303	.128	-.215	.056	.098
28	.276	.134	.366	.200	.145	.176	.096	.110	.400	.387	.047	.032	.363	.375	.326	-.320	.241	.269
29	.106	.249	.095	.044	.004	-.036	.024	-.004	-.026	.123	-.125	.096	-.005	-.029	.161	.056	.027	-.039
30	.086	.150	.185	.204	.023	.228	-.082	.086	.021	.155	.183	.276	.117	.249	.201	-.384	.172	.213
31	.007	.022	-.147	.024	-.238	-.153	.062	-.014	-.177	-.181	-.117	.138	-.089	-.078	-.021	.096	-.050	-.087
32	-.130	-.186	-.192	-.106	-.173	-.043	-.084	-.013	.000	-.080	-.078	-.021	-.166	-.084	-.107	.151	-.119	-.278
33	-.240	-.264	-.053	.094	.130	.142	.090	-.027	-.126	-.260	.017	-.011	-.156	-.226	-.335	.241	-.243	-.228
34	-.223	-.174	-.333	-.129	.070	-.058	-.023	.017	-.248	-.184	-.284	-.086	-.211	-.194	-.211	.142	-.083	-.199
35	-.281	-.173	-.553	.402	-.018	-.363	-.138	-.125	-.345	-.449	-.401	-.274	-.167	-.453	-.204	.422	-.331	-.509

(Continued)

18	.395	.339	.243	.244	-.121	.209	.145	.242	.234	.341	.186	.049	.267	.498	.212	-.462	.676	
19	-.301	-.196	-.314	-.111	-.041	-.177	.040	-.184	-.289	-.431	-.113	-.131	-.432	-.524	-.371	.502	-.297	-.374
20	.399	.318	.184	.131	.098	.163	.145	.282	.231	.239	.108	-.032	.331	.473	.026	-.413	.335	.444
21	.162	.301	.044	.152	-.025	.086	-.020	.180	.274	.050	-.052	-.026	-.025	.110	.219	-.014	.082	.126
22	.468	.303	.160	.199	-.006	.238	.101	.207	.429	.320	.022	.042	.412	.451	.146	-.345	.329	.414
23	-.080	-.005	-.303	-.121	-.156	-.107	.124	-.049	-.132	.010	-.159	-.062	-.193	-.159	-.071	.283	-.184	-.243
24	.397	.313	.291	.025	.082	.077	.052	.062	.233	.358	.058	.022	.270	.447	.207	-.401	.281	.317
25	-.221	-.010	.100	.035	-.125	-.016	-.158	.000	-.076	.145	.119	.044	-.170	-.079	-.009	-.070	-.001	-.001
26	.057	.026	-.154	-.190	-.028	-.095	-.029	-.014	-.243	.020	-.091	.112	.044	-.171	-.075	.134	.028	-.162
27	.162	.022	.311	.007	.091	.050	-.129	-.061	.160	.336	.033	.121	.246	.303	.128	-.215	.056	.098
28	.276	.134	.366	.200	.145	.176	.096	.110	.400	.387	.047	.032	.363	.375	.326	-.320	.241	.269
29	.106	.249	.095	.044	.004	-.036	.024	-.004	-.026	.123	-.125	.096	-.005	-.029	.161	.056	.027	-.039
30	.086	.150	.185	.204	.023	.228	-.082	.086	.021	.155	.183	.276	.117	.249	.201	-.384	.172	.213
31	.007	.022	-.147	.024	-.238	-.153	.062	-.014	-.177	-.181	-.117	.138	-.089	-.078	-.021	.096	-.050	-.087
32	-.130	-.186	-.192	-.106	-.173	-.043	-.084	-.013	.000	-.080	-.078	-.021	-.166	-.084	-.107	.151	-.119	-.278
33	-.240	-.264	-.053	.094	.130	.142	.090	-.027	-.126	-.260	.017	-.011	-.156	-.226	-.335	.241	-.243	-.228
34	-.223	-.174	-.333	-.129	.070	-.058	-.023	.017	-.248	-.184	-.284	-.086	-.211	-.194	-.211	.142	-.083	-.199
35	-.281	-.173	-.553	.402	-.018	-.363	-.138	-.125	-.345	-.449	-.401	-.274	-.167	-.453	-.204	.422	-.331	-.509

(Continued)

Table 3 (Continued)
Product-Moment Correlations for the Thirty-Five Variables

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1																	
2																	
3																	
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17																	
18																	
19																	
20	-.242																
21	-.216	.067															
22	-.290	.470	.190														
23	.189	-.165	.005	-.107													
24	-.448	.213	.184	.379	-.130												
25	-.097	-.146	.066	-.058	-.130	.137											
26	.162	-.053	-.163	-.060	.012	.066	.200										
27	-.424	.019	.066	.208	.013	.392	.042	-.133									
28	-.485	.268	-.001	.353	-.089	.420	-.112	-.139	.473								
29	.004	-.020	-.075	.072	.033	.074	.130	.110	-.031	.082							
30	-.251	.190	-.066	.130	-.190	.127	.146	-.124	.096	.158	.170						
31	.076	-.050	.081	-.203	-.001	-.192	.001	-.053	-.282	-.221	.039	-.125					
32	.124	-.225	-.097	-.200	.069	-.177	-.041	.046	-.172	-.092	-.050	-.273	.317				
33	.426	-.133	-.140	-.171	-.077	-.252	-.047	.114	-.268	-.204	.069	-.242	.120	.126			
34	.411	-.023	.005	-.174	.184	-.199	-.048	.160	-.337	-.261	.088	-.171	.056	.085	.451		
35	.445	-.361	-.041	-.415	.211	-.344	-.122	.131	-.300	-.462	-.014	-.213	.252	.189	.194	.445	

Table 4
Promax Factors
Structure on the Reference Matrix

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	.498	.103	-.138	-.088	.021	-.022	.158	.136	-.067	-.006	.234	-.011
2	.254	-.043	-.078	-.192	.144	.112	.300	.318	.063	-.111	.068	-.011
3	.016	.305	.522	.001	-.003	.056	-.082	.114	.059	-.017	.190	.250
4	.043	-.009	.493	.068	.122	-.027	.119	.117	-.103	.005	.001	.034
5	-.138	.169	-.001	.211	.016	.312	.056	.014	-.100	-.126	-.064	.297
6	.210	.076	.372	.232	.031	.020	-.070	-.028	-.047	.106	-.068	.028
7	.068	-.115	.149	.026	-.035	-.008	-.047	.014	-.113	.028	.512	.089
8	.180	-.081	.028	.044	.045	-.061	.479	.001	.058	.036	-.131	.003
9	.012	.276	.151	-.047	.194	-.037	.446	-.011	-.154	-.007	.067	-.020
10	.266	.395	.136	-.062	-.080	-.052	.160	.088	.198	.077	-.142	-.225
11	-.047	-.058	.473	-.137	-.164	.052	.354	-.127	.107	-.032	.063	.148
12	-.073	.020	.034	.018	.082	.024	-.010	-.075	.071	.670	.016	-.020
13	.449	.213	-.306	-.086	-.094	.004	.005	-.021	-.108	.059	.111	.179
14	.597	.228	.082	-.014	-.003	-.094	-.008	-.052	-.085	.097	-.001	.117
15	-.018	.115	.131	-.337	.138	-.033	-.011	.270	-.027	.112	.209	-.004
16	-.545	-.127	-.132	.077	.049	.036	.051	.055	-.047	-.052	.203	-.251
17	.602	-.007	.241	-.020	-.003	-.021	-.007	.039	.084	-.173	-.036	-.070
18	.657	-.078	.313	-.124	.041	.092	-.015	-.097	.017	-.056	.104	-.052
19	-.252	-.446	-.026	.283	-.114	.098	-.044	.006	-.048	-.066	.154	-.218
20	.549	-.038	.028	.097	-.049	.115	.196	-.018	-.133	-.035	.020	.116
21	.010	-.028	-.008	.003	.839	.023	.099	-.076	.042	.042	-.012	.011
22	.443	.212	.054	.092	.113	.102	.150	.032	-.082	.056	.082	-.058
23	-.141	.032	-.130	-.062	-.023	.036	-.017	.067	-.157	-.004	-.097	-.537
24	.296	.434	-.046	-.040	.121	.109	-.032	.056	.249	-.084	.044	.125
25	-.113	.020	.100	-.051	.096	-.021	.001	.081	.636	.002	-.216	.143
26	.044	-.074	-.277	.192	-.115	.037	.002	.094	.471	.108	.095	.009
27	-.012	.667	-.005	-.205	.001	.164	-.108	-.072	-.012	-.018	-.125	-.043
28	.138	.618	.166	-.024	-.077	-.020	.054	.171	-.190	-.044	.050	.015
29	-.063	.075	.028	.091	-.095	-.035	-.018	.674	.127	-.052	-.018	-.046
30	.102	-.123	.154	-.253	-.097	.212	.012	.340	-.048	.387	-.390	.194
31	.035	-.315	-.055	-.131	.061	-.518	-.073	.083	-.038	-.108	.058	.085
32	-.130	.035	-.053	.139	-.072	-.632	.086	-.037	.006	-.025	-.022	-.037
33	-.143	-.152	.144	.730	-.009	-.032	.014	.029	.022	.037	.136	.124
34	.052	-.276	.193	.500	.098	.008	-.092	.121	.006	-.008	-.104	-.090
35	-.233	-.318	-.592	.054	.062	-.060	-.086	.048	-.068	-.142	-.173	.026

18	.657	-.078	.313	-.124	.041	.092	-.015	-.097	.017	-.056	.104	-.052
19	-.252	-.446	-.026	.283	-.114	.098	-.044	.006	-.048	-.066	.154	-.218
20	.549	-.038	.028	.097	-.049	.115	.196	-.018	-.133	-.035	.020	.116
21	.010	-.028	-.008	.003	.839	.023	.099	-.076	.042	.042	-.012	.011
22	.443	.212	.054	.092	.113	.102	.150	.032	-.082	.056	.082	-.058
23	-.141	.032	-.130	-.062	-.023	.036	-.017	.067	-.157	-.004	-.097	-.537
24	.296	.434	-.046	-.040	.121	.109	-.032	.056	.249	-.084	.044	.125
25	-.113	.020	.100	-.051	.096	-.021	.001	.081	.636	.002	-.216	.143
26	.044	-.074	-.277	.192	-.115	.037	.002	.094	.471	.108	.095	.009
27	-.012	.667	-.005	-.205	.001	.164	-.108	-.072	-.012	-.018	-.125	-.043
28	.138	.618	.166	-.024	-.077	-.020	.054	.171	-.190	-.044	.050	.015
29	-.063	.075	.028	.091	-.095	-.035	-.018	.674	.127	-.052	-.018	-.046
30	.102	-.123	.154	-.253	-.097	.212	.012	.340	-.048	.387	-.390	.194
31	.035	-.315	-.055	-.131	.061	-.518	-.073	.083	-.038	-.108	.058	.085
32	-.130	.035	-.053	.139	-.072	-.632	.086	-.037	.006	-.025	-.022	-.037
33	-.143	-.152	.144	.730	-.009	-.032	.014	.029	.022	.037	.136	.124
34	.052	-.276	.193	.500	.098	.008	-.092	.121	.006	-.008	-.104	-.090
35	-.233	-.318	-.592	.054	.062	-.060	-.086	.048	-.068	-.142	-.173	.026

Table 5
Promax Transformation Matrix

.635	-.034	-.019	.032	-.026	-.007	-.023	-.020	-.005	-.016	.001	.002
-.064	.513	-.002	.016	-.014	-.021	-.007	.002	.010	-.047	.003	-.006
-.022	.003	.444	.045	.006	-.023	-.004	.026	-.033	-.021	.002	-.012
.065	.013	-.006	.516	.044	-.013	-.004	.003	.016	-.008	.002	.010
-.037	-.025	-.031	.038	.685	.013	-.012	-.027	.020	.036	.011	.011
-.033	-.006	-.008	-.026	.019	.507	-.002	-.013	-.008	.013	-.013	-.002
-.090	-.020	-.016	-.005	-.028	-.022	.395	.001	.021	.016	-.034	.001
-.074	.018	.000	.031	-.052	-.028	.001	.464	.016	.014	-.018	-.007
.020	-.008	.014	.027	.026	.004	-.003	-.009	.415	-.017	.000	.024
-.056	-.046	-.027	.019	.076	-.002	-.010	-.002	.003	.524	-.000	-.010
-.013	-.051	.068	.024	-.011	-.007	-.026	-.020	-.018	.030	.313	.004
-.027	-.019	-.044	.038	.038	-.036	.018	-.010	.057	-.016	-.014	.338

Table 6
Correlation between Reference Axes Promax Rotation

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000	-.143	-.057	.137	-.081	-.047	-.189	-.150	.004	-.118	.006	-.024
2	-.143	1.000	.004	.039	.076	-.050	-.044	.052	.006	.180	-.085	-.056
3	-.057	.004	1.000	.063	-.070	-.055	-.052	.057	-.070	-.092	.162	-.126
4	.137	.039	.063	1.000	.136	-.086	-.026	.061	.096	.016	.052	.103
5	-.081	-.076	-.070	.136	1.000	.054	-.068	-.131	.087	.170	.024	.089
6	-.047	-.050	-.055	-.086	.054	1.000	-.050	-.084	-.022	.026	-.042	-.072
7	-.189	-.044	-.052	-.026	-.068	-.050	1.000	.011	.050	.003	-.174	.046
8	-.150	.052	.057	.061	-.131	-.084	.011	1.000	.011	.016	-.098	-.049
9	.004	.006	-.070	.096	.088	-.022	.050	.011	1.000	-.025	-.053	.207
10	-.118	-.180	-.092	.016	.170	.026	.003	.016	-.025	1.000	.051	-.056
11	.006	-.085	.162	.052	.024	-.042	-.174	-.098	-.053	.051	1.000	-.029
12	-.024	-.056	-.126	.103	.089	-.072	.046	-.049	.207	-.056	-.029	1.000

5	-.081	-.076	-.070	.136	1.000	.054	-.068	-.131	.087	.170	.024	.089
6	-.047	-.050	-.055	-.086	.054	1.000	-.050	-.084	-.022	.026	-.042	-.072
7	-.189	-.044	-.052	-.026	-.068	-.050	1.000	.011	.050	.003	-.174	.046
8	-.150	.052	.057	.061	-.131	-.084	.011	1.000	.011	.016	-.098	-.049
9	.004	.006	-.070	.096	.088	-.022	.050	.011	1.000	-.025	-.053	.207
10	-.118	-.180	-.092	.016	.170	.026	.003	.016	-.025	1.000	.051	-.056
11	.006	-.085	.162	.052	.024	-.042	-.174	-.098	-.053	.051	1.000	-.029
12	-.024	-.056	-.126	.103	.089	-.072	.046	-.049	.207	-.056	-.029	1.000

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. This interpretation is suggested particularly by variables 18, 17, 1, 13, and 22. These tests would seem to require an integration or organization of the perceptual information received.

The interpretation of this factor was made difficult by the apparent memory component in the high loading variables. This suggested, however, that perceptual organization or integration would facilitate proficiency on those tests involving a memory component. The emphasis on organization rather than the perceptual aspects was made evident by the near zero loadings of strictly perceptual tests such as Retinal Rivalry (3), Halstead's Rhythm Test (15), and Halstead's Speech Sounds Test (21). It might be interesting to include in a future analysis the Block Design and Object Assembly sub-tests of the WAIS which have consistently been used to identify a perceptual organization factor in analyses of the WAIS. The identification of the same factor with high loadings on these sub-tests would tend to corroborate the present interpretation.

FACTOR II

Eight variables have loadings above .30 on Factor II. These are:

27. Purdue Pegboard—Total	+.667
28. Purdue Pegboard—Assemblies	+.618
19. Trail Making Latency	—.446
24. Grayson Perceptualization	+.434
10. Symbol Gestalt	+.395
35. Age	—.318
31. Muller-Lyer-Error	—.315
3. Retinal Rivalry	+.305

This factor is interpreted as perceptual-motor speed. The high loading variables on this factor would seem to require an integrated perceptual-motor response under speeded conditions. The importance of the perceptual aspect of this factor is indicated by the high loadings of variables 19, 24, and 10, which appear to depend more heavily upon perceptual information than motor coordination, and the loading of tests 31 and 3, which do not require a motor response.

FACTOR III

This factor is interpreted as temporal perceptual resolution. The relevant high loading variables are:

35.	Age	−.592
3.	Retinal Rivalry	+.522
4.	Modified Word Learning	+.493
11.	C.F.F.—Mean	+.473
6.	Organic Integrity	+.372
18.	Tactual Performance—Localization	+.313
13.	Porteus Mazes	−.306

The title of this factor is meant to be descriptive of a perceptual phenomenon analogous to the resolving capacity used to describe visual resolution (Westheimer, 1965). The purely sensory use of the term resolving capacity could be considered in terms of at least two dimensions: Temporal and spatial. Temporal resolution for visual phenomenon would include such measures as the critical flicker frequency, while a measure of spatial resolution for the same modality would be the Landoldt C. The interpretation of temporal perceptual resolution was meant to indicate a perceptual source of variance analogous to the temporal dimension of resolving capacity. This particular interpretation was suggested by the high loading tests, such as variables 3, 4, and 11, which are more perceptual than sensory in nature, and by variables 3 and 11 which seem to require a perceptual form of resolving power. This factor would appear to be most similar to Halstead's Power Factor (Halstead, 1947). The type of tests loading his Power Factor and what has been termed a perceptual resolution factor are at least superficially similar.

The high negative loading of age on Factor III suggests that the factor is particularly sensitive to differences in age. This finding is consistent with studies reporting a monotonic decline as a function of age for one of the measures, critical flicker frequency.

The one test loading that initially appeared to be inconsistent with the interpretation was Modified Word Learning (4). The high loading of this variable could be explained, however, by the manner of presentation. The words and meanings are presented verbally to the *S*, and he is required to memorize these meanings. It is suggested that an important aspect of the test situation is *S*'s reception of the orally presented test material. Variability associated with reception could account for part of the variability in scores obtained for the *S*s tested.

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	—.592
	+.522
	+.493
	+.473
	+.372
lization	+.313
	—.306

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FACTOR IV

The high loading variables for Factor IV are:

33. Simple Reaction Time	+.730
34. Choice Reaction Time	+.500
15. Halstead Rhythm Test	—.337

This factor is considered to be uninterpretable in this battery for at least two reasons. In addition to being minimally determinate, there is a possibility of experimental dependence between the two reaction time variables. The high loading variables do suggest, however, a speed or timing factor.

FACTOR V

Factor V is considered to be unique in this battery. Only one test has a projection above .30 and that is Halstead's Speech Sounds Test with a loading of .839. The inclusion of other comprehension tests such as have been studied by Schuell, Jenkins, and Carroll (1962) might provide a basis for identification of this factor.

FACTOR VI

Three variables have loadings above .30 on this factor. These are:

32. Muller-Lyer—Difference	—.632
31. Muller-Lyer—Error	—.518
5. Apparent Motion	+.312

This factor is considered to be uninterpretable because of relative underdetermination and possible experimental dependence. One could speculate that the high loading variables suggest a bipolar illusion factor. This speculation, however, would be based on the apparent content of the high loading variables which could be misleading without other sources of possible identification.

FACTORS VII-XII

The remaining factors extracted in the 16-70 age group analysis are considered uninterpretable. They consist of triplet factors combined with the possibility of experimental dependence, and doublet or unique factors. The high loading variables of these factors are indicated in Table 7.

Table 7
High Loading Variables for Factors VII-XII

Factor	Variables	Projection
VII	Grassi-Accuracy	+.479
	Grassi-Time Credits	+.446
	C.F.F. Mean	+.354
VIII	Kahn Test—Symbolization	+.674
	Kahn Test—Recall	+.340
	Proverbs	+.318
IX	Sound Localization—Separation	+.636
	Sound Localization—Localization	+.471
X	C.F.F. Deviation	+.670
	Kahn Test—Recall	+.387
XI	Binaural Beats	+.512
	Kahn Test—Recall	—.390
XII	Minnesota Percepto-Diagnostic	—.537

The factorial complexity of the thirty-four variables is given in Table 8. The Varimax rather than the Promax solution was selected for this particular analysis to avoid possible misinterpretation of communality values in the oblique solution. Only those factors having loadings greater than ± .300 were considered.

Table 8
Factorial Complexity of the Thirty-Four Variables
Based on the Orthogonal Solution

TEST	FACTOR(S)	h^2	TEST	FACTOR(S)	h^2
1	1	.608	18	1, 3	.700
2	1, 7, 8	.569	19	2, 1, 4	.666
3	2, 3	.577	20	1	.506
4	3	.349	21	5	.782
5	6, 12	.345	22	1	.496
6	3	.306	23	12	.379
7	11	.312	24	2, 1	.517
8	7	.332	25	9	.503
9	7, 2	.501	26	9, 3	.415
10	2, 1	.527	27	2	.582
11	3, 7	.503	28	2	.619
12	10	.502	29	8	.483
13	1	.534	30	8, 10, 11, 4	.764
14	1	.640	31	6, 2	.483
15	4	.403	32	6	.491
16	1	.603	33	4	.686
17	1	.529	34	4, 2	.491

7
'or Factors VII-XII

	Projection
	+.479
	+.446
	+.354
n	+.674
	+.340
	+.318
ration	+.636
lization	+.471
	+.670
	+.387
	+.512
	—.390
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Thirty-Four Variables
onal Solution

TEST	FACTOR(S)	h^2
18	1, 3	.700
19	2, 1, 4	.666
20	1	.506
21	5	.782
22	1	.496
23	12	.379
24	2, 1	.517
25	9	.503
26	9, 3	.415
27	2	.582
28	2	.619
29	8	.483
30	8, 10, 11, 4	.764
31	6, 2	.483
32	6	.491
33	4	.686
34	4, 2	.491

When such a criterion is used only 13 of the 34 variables have a factorial complexity greater than one. It should be noted, however, that the mean communality value for the remaining 21 variables is only .507. There is a possibility that other components could not be identified because the appropriate marker variables were not included in the test battery.

The final analysis of the data involved the determination of factor score estimates for each individual on each of the factors retained. The plots of these factor scores as a function of age is given in Figures 1, 2, and 3 for the interpretable factors. Analyses of variance performed for factor score differences for all 12 factors revealed significant changes for only two. The decline observed for Factor II was found to be significant ($F = 4.15$, $p < .01$; 7, 92 df) as was the decline for Factor III ($F = 11.81$, $p < .01$; 7, 92 df). These factors have been termed the perceptual-motor speed and temporal perceptual resolution factors respectively.

Further evidence of the significant difference as a function of age for Factors II and III is given by the negative loading of age on these factors. As outlined in Table 4 the age variable has a projection of —.318 on Factor II and —.592 on Factor III These results represent a more direct indication of the difference since the observed loadings represent the correlation between age and the true factor scores, whereas the obtained factor scores are only estimates of these true factor scores.

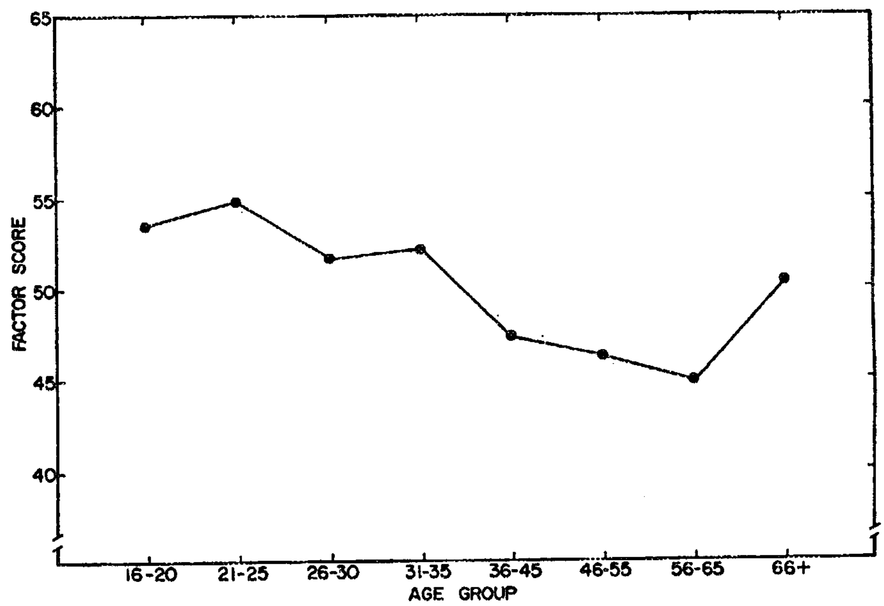


Fig. 1 Factor I Scores as a Function of Age

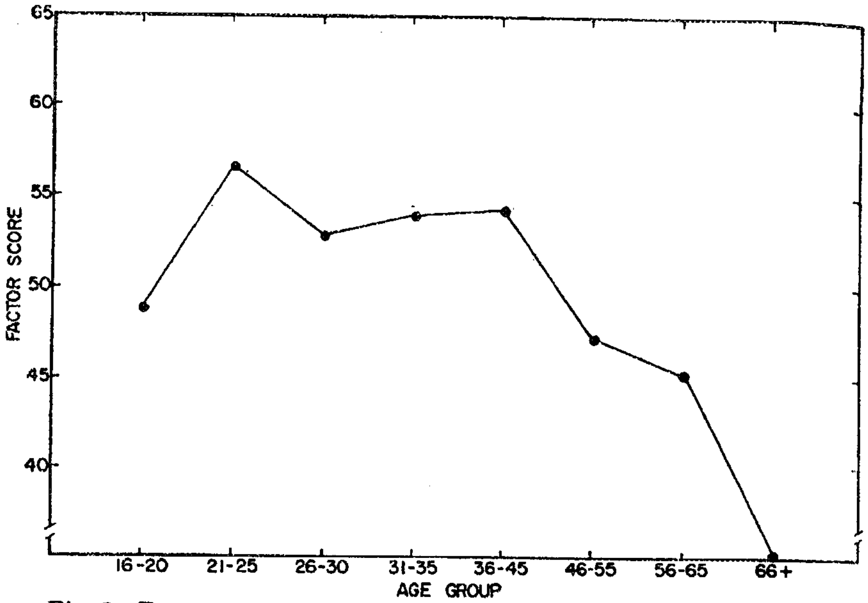


Fig. 2 Factor II Scores as a Function of Age

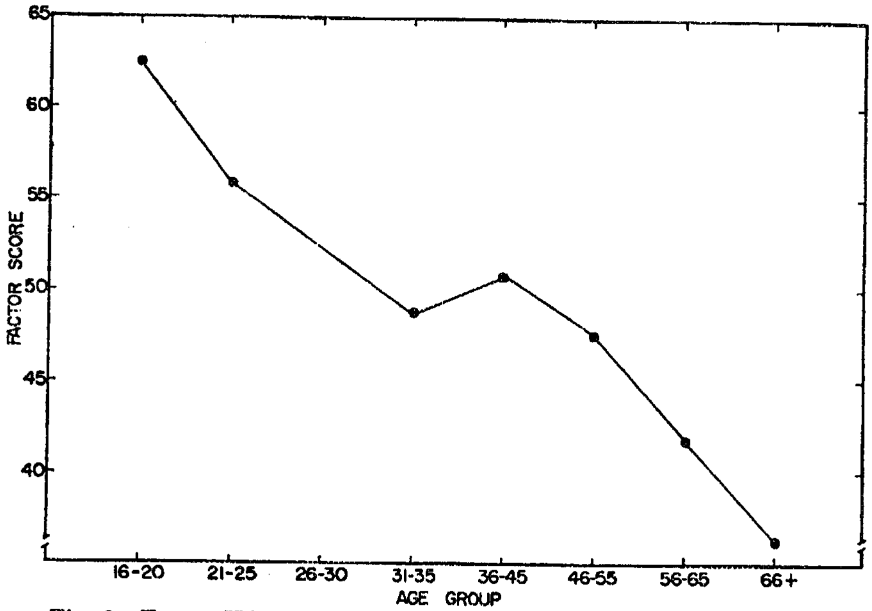
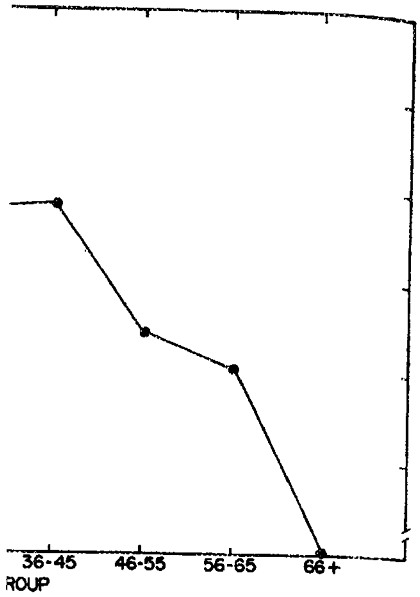


Fig. 3 Factor III Scores as a Function of Age

Discussion

The factorial analysis of the brain damage test battery for the 16-70 age group indicates that the factorial composition of the battery is relatively complex when administered to normal indi-



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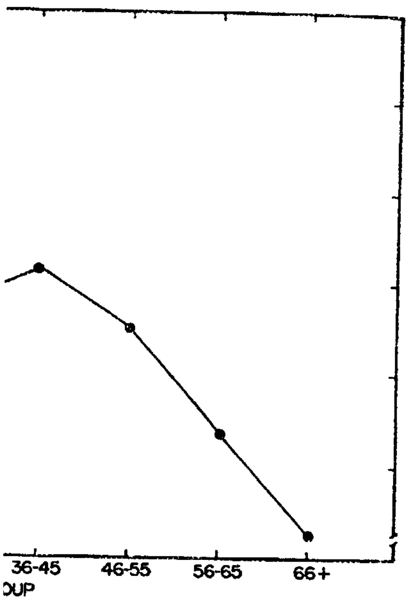

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viduals. The number of dimensions that could be identified was less than the number of factors retained, however, which suggests that several dimensions are not being adequately sampled by valid and reliable instruments presently being used.

All the tests included in the present battery have been found to discriminate between brain damaged and normal individuals. If one could assume that these discriminations are being made on the basis of dimensions identified in this study, it would appear that many of the dimensions of interest are only partially sampled by this test battery. This would be evident from that fact that nine of the twelve factors extracted could not definitely be identified. The evidence provided by this analysis in conjunction with the assumption made, suggest the importance of studying the factorial composition of the tests for groups of normals and individuals with specific lesions. A test of the assumption would involve a comparison of the factors extracted for the two differently constituted groups. If the comparison indicated a high degree of similarity, then some of the factors which were underdetermined in this battery should be investigated further. This would mean that the test battery would be augmented with tests similar to the ones which indicated important sources of variance, but which could not be identified in the present battery.

Factor analytic studies of the WAIS administered to both normals and brain damaged groups have indicated substantial similarity in factor structures (Cohen, 1952; Berger *et al.*, 1964). In fact, in the Berger *et al.* study the authors concluded that differences observed over age were greater than that found for normal and brain damaged groups. In view of these suggestive findings further study of the possible dimensions of discrimination between normals and brain damaged groups would be warranted.

The results of this study also indicate a duplication in terms of the number of tests which discriminate on the basis of the same continua in normal samples. Nineteen of the tests included in the battery had substantial projections on one or other of the first three factors extracted. These factors were all interpreted as having a perceptual component, which could suggest the importance assigned to perceptual activities in the construction of brain damage tests. If one could assume that the sources of variance observed in this study are also the important dimensions of discrimination between normals and brain damage groups, then these results would suggest that differences in perception, and perceptual functioning integrated with response components, form an important aspect in the discrimination between these groups.

The relationship of the factors extracted in this study to those found in earlier factor analytic studies of brain damage tests would be difficult to assess. One possibly important difference was the use of a normal sample in this study as contrasted with brain damaged and other pathological groups in previous studies (Halstead, 1947; Jones and Wepman, 1961; Schuell, Jenkins, and Carroll, 1962; Coppinger, Bortner, and Saucer, 1963). A factor analytic study reported by Berger *et al.* (1964) has suggested a high degree of factor comparability between normals and brain damaged individuals for performance on the WAIS. Whether or not such a conclusion can be drawn for the tests used in this study awaits empirical investigation. A more critical difference obviating comparison between studies concerns the tests included for study. The Jones and Wepman (1961) and Schuell, Jenkins, and Carroll (1962) studies were concerned with tests of aphasia. In terms of the criteria outlined for the selection of tests in this study (Royce and Carran, 1964) the aphasia tests had not been included.

Although the tests included in the Coppinger *et al.* (1963) study were essentially different, one of the factors extracted appears to bear at least a superficial resemblance to the Perceptual Resolution factor interpreted in this study. The factor reported in the Coppinger *et al.* study was interpreted as "sensory alertness and includes loadings of C.F.F., Age, and a variable termed Shortest Noticeable Dark Time. The inclusion of different content tests in the two studies precluded any further subjective comparisons between factors.

Perhaps the greatest degree of similarity between factors would have been expected in a comparison of Halstead's study (Halstead, 1947) and the present analysis. This expectation was based on the fact that many of Halstead's variables were included in the present battery. Inspection of the high loading variables in the factor matrices suggested a similarity only between Halstead's Factor P and the temporal Perceptual Resolution Factor observed in this study. A more direct comparison could not be applied since the number of variables used in the two studies were different and the number of factors extracted in this study was much greater than was found in Halstead's study.

The analysis of the factorial complexity of the tests in the battery suggested that at least for some of the more widely used

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nplexity of the tests in the
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tests the complexity is greater than one. Reitan's Trail Making Test (Reitan, 1955), for example, has a complexity of three in the orthogonal solution which would suggest that this particular test would not be appropriate for identifying specific lesions. For the remaining tests one cannot conclude their complete appropriateness since in general the communality values were relatively low. Further study of this important problem might consider the reliability of each of the tests and attempt to identify other sources of variance not isolated in this study.

The different declines observed for the factor scores of the factors extracted would suggest that certain of the tests would be psychometrically more efficient for older age groups. By a psychometrically efficient brain damage test is meant one which discriminates between normals and brain damaged persons. In this sense a test loading highly on Factor I would be more efficient for older age groups than a test loading Factor III. If the tests loading the two factors have equal validity for brain damage it would be reasonable to select a test with a high loading on Factor I for an older person since a large part of the variance observed in test scores is not systematically associated with age. A low score on a test with substantial loading on Factor III, on the other hand, could be attributed to age.

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