Discriminant Function Analysis of Performance by Normals and Left Hemisphere, Right Hemisphere, and Bilaterally Brain Damaged Patients on a Word Fluency Measure

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We often ask our patients to produce a second form of identification. Biographic and medical histories are taken, neurologic and radiographic evaluations are perused, and patients are immersed in a psychometric marinade. Jay Rosenbek suggests, quite correctly, that history is everything, and standardized measures may make dissimilar conditions look similar. Nevertheless, we cull our measures to look for confirmation, a second form of identification.

One of the most popular and most perplexing things we may do with brain damaged adults is to administer a Word Fluency Measure. Fred Darley has gently inquired, "What in the hell does that thing tell us?" Darley is the E.F. Hutton of Aphasiology. When he talks, we usually listen. And, when he asks, some of us are prompted to answer.

Word Fluency Measures are popular in the appraisal of brain damaged adults. Two standardized tests for aphasia, the Boston Diagnostic Aphasia Examination (Goodglass and Kaplan, 1983) and the Western Aphasia Battery (Kertesz, 1982), contain a Word Fluency Measure that requires the patient to produce names of animals. Another test, the Neurosensory Center Comprehensive Examination for Aphasia (Spreen and Benton, 1969), requires the patient to produce words that begin with specified letters of the alphabet. The Mattis Dementia Rating Scale (Mattis, 1976) tests patients' ability to name items found in a supermarket.

Investigations comparing normals with groups of brain damaged adults (Borkowski, Benton, and Spreen, 1967; Bayles and Tomoeda, 1983; Collins et al., 1984; Wertz et al., 1985; Ober, et al., 1986) show that brain damaged subjects produce significantly fewer words than normals. Those who have used a Word Fluency Measure to differentiate within and among groups of brain damaged patients report mixed results. Bayles and Tomoeda (1983) found that a Word Fluency Measure showed significant differences between a group of mildly demented patients and a group of moderately demented patients. Collins et al. 1984) found no significant difference in word fluency performance among groups of Broca's, Wernicke's, and unclassifiable aphasic patients. We (Wertz et al., 1985) reported that word fluency performance by right hemisphere and bilaterally brain damaged patients was significantly better than performance by left hemisphere brain damaged patients, but that right hemisphere and bilateral groups did not differ significantly in performance. Ober et al. (1986) found significant differences among groups of normals and mildly impaired and moderately impaired patients with probable Alzheimer's disease on three types of word fluency tasks.

If one is interested in a test's ability to discriminate among groups, an appropriate statistical procedure is discriminant function analysis. To our knowledge, this approach has not been used to compare word fluency performance among groups of normals and brain damaged adults. The purpose of this paper is to report the results of a discriminant function analysis of word fluency performance by normal adults and groups of left hemisphere, right hemisphere, and bilaterally brain damaged adults.

METHOD

Four groups participated in the study: 40 normal adults with no history of neurologic involvement, 40 adults who had suffered left hemisphere brain damage, 40 adults who had suffered right hemisphere brain damage, and 40 adults who had suffered bilateral brain damage.

Cause of brain damage was cerebral vascular accident in all left hemisphere and right hemisphere patients. Eighteen bilateral patients suffered multiple CVAs, 17 suffered bilateral traumatic brain injury, and five displayed bilateral diffuse cortical atrophy. Localization data were provided by clinical neurologic evaluation and neuroradiologic results.

Group descriptive data are shown in Table 1. Kruskal-Wallis analysis with Nemenyi post hoc comparisons revealed the bilateral group was significantly younger than all other groups, and the brain damaged groups did not differ significantly in time postonset. Analysis of variance yielded no significant differences among groups in years of education.

Table 1. Group descriptive data.

GROUP	AGE		EDUCATION		MONTHS POSTONSET	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Normal	59.2	13.9	13.3	2.6	-	-
Left Hemipshere	59.4	11.3	12.4	2.5	23.0	37.3
Right Hemisphere	56.5	13.8	12.2	2.6	11.3	15.0
Bilateral	47.8	17.9	13.0	2.5	18.8	27.5

Our Word Fluency Measure required each subject to produce all of the words he or she could think of in one minute beginning with a specified letter of the alphabet. Four letters--S, T, P, C--were used, and the total number of words produced for all four letters was analyzed. These data were entred into a discriminant function analysis to determine the percentage of patients that were classified correctly into their respective groups.

RESULTS

Group performance on the total number of words produced, shown in Table 2, revealed a wide range among and within groups. Mean total word production was greatest in the normal group, followed by the right hemisphere, bilateral, and left hemisphere groups. However, when the bilateral group was divided by cause of brain damage into traumatic brain injury (TBI) and multiple infarcts, the TBI patients were superior to right hemisphere patients, followed by bilateral multi-infarct patients and left hemisphere patients.

Table 2. Word Fluency Measure group performance.

GROUP		TOTAL WORDS	
	$\bar{X}$	Range	S.D.
Normal	51.9	22 - 88	16.2
Left Hemisphere	12.9	0 - 63	13.5
Right Hemisphere	38.7	13 - 76	16.2
Bilateral	31.4	0 - 68	20.2
TBI (N = 17)	43.0	15 - 68	17.2
MI (N = 18)	22.4	0 - 48	16.6

Nemenyi paired comparisons (Table 3) indicated that the normal group produced significantly more words than each of the other groups. Both right hemisphere patients and bilateral patients produced significantly more words than left hemisphere patients, but the right hemisphere and bilateral groups did not differ significantly from each other.

Table 3. Word Fluency Measure group comparisons.

COMPARISON	MEAN DIFFERENCE
Normal - Left Hemisphere	39.0*
Normal - Right Hemisphere	13.2*
Normal - Bilateral	20.5*
Right Hemisphere - Left Hemisphere	25.8*
Bilateral - Left Hemisphere	18.5*
Right Hemisphere - Bilateral	7.3

*Significant at $p < .05$ (Experiment-wise error rate = .05)

When the bilateral group was divided by cause of brain damage (Table 4), the group comparisons changed. Scheffe comparisons revealed that normals produced significantly more words than multi-infarct patients but not TBI patients. Right hemisphere patients produced significantly more words than multi-infarct patients but not TBI patients. TBI patients produced significantly more words than left hemisphere patients, but multi-infarct patients did not differ significantly from left hemisphere patients. TBI patients performed significantly better than multi-infarct patients.

Table 4. Word Fluency Measure group comparisons when the bilateral group wa divided by etiology.

COMPARISON	MEAN DIFFERENCE
Normal - Traumatic Brain Injury	8.9
Normal - Multi-Infarct	29.5*
Traumatic Brain Injury - Right Hemisphere	4.3
Right Hemisphere - Multi-Infarct	16.3*
Traumatic Brain Injury - Left Hemisphere	30.0*
Multi-Infarct - Left Hemisphere	9.5
Traumatic Brain Injury - Multi-Infarct	20.6*

*Significant at $p < .05$ (Experiment-wise error rate = .05)

Because performance on the Word Fluency Measure is reported to be a sensitive indication of brain damage, our first discriminant function analysis compared the 40 normals with the 120 brain damaged patients. Table 5 shows that 31 (77.5 percent) of the normals were classified as normal, and 9 (22.5 percent) were classified as brain damaged. Eighty-four (70 percent) of the brain damaged patients were classified as brain damaged, and 36 (30 percent) were classified as normal. Thus, 115 of the 160 cases (71.9 percent) were classified correctly, and 45 cases (28.1 percent) were classified incorrectly.

Table 5. Discriminant function analysis classification of normals and all brain damaged patients.

ACTUAL GROUP	PREDICTED GROUP MEMBERSHIP	
	Normal	Brain Damaged
Normal (N = 40)		
Number of Cases	31	9
Percent of Cases	77.5	22.5
Brain Damaged (N = 120)		
Number of Cases	36	84
Percent of Cases	30.0	70.0

Percent of all cases classified correctly = 71.9

The second discriminant function analysis (Table 6) was run on four groups--normal left, right, and combined bilaterals. Seventy-six of 160 cases (47.5 percent) were classified correctly, and 84 cases (52.5 percent) were classified incorrectly. Classification was most accurate for left hemisphere patients (80 percent) followed by normals (65 percent), Right hemisphere patients (25 percent), and bilateral patients (20 percent). One of the normals was classified as having left hemisphere brain damage, and one left hemisphere patient was classified as normal. Right hemisphere patients were more often classified as normal or bilateral than they were as right hemisphere. Similarly, bilateral patients were more often classified as normal or left hemisphere than they were as bilateral.

Table 6. Discriminant function analysis classification of normals and left hemisphere, right hemisphere, and bilateral brain damaged patients.

ACTUAL GROUP	PREDICTED GROUP MEMBERSHIP			
	Normal	Left	Right	Bilateral
Normal (N = 40)				
Number of Cases	26	1	8	5
Percent of Cases	65.0	2.5	20.0	12.5
Left Hemisphere (N = 40)				
Number of Cases	1	32	2	5
Percent of Cases	2.5	80.0	5.0	12.5
Right Hemisphere (N = 40)				
Number of Cases	12	7	10	11
Percent of Cases	30.0	17.5	25.0	27.5
Bilateral (N = 40)				
Number of Cases	11	15	6	8
Percent of Cases	27.5	37.5	15.0	20.0

Percent of all cases classified correctly = 47.5

The third discriminant function analysis (Table 7) was run on five groups--normal, left hemisphere, right hemisphere, bilateral multi-infarct, and bilateral traumatic brain injury. Sixty-nine (44.5 percent) of 155 cases were classified correctly, and 86 cases (55.5 percent) were classified incorrectly. Classification was most accurate for left hemisphere patients (72.5 percent), followed by normals (60 percent), right hemisphere patients (25 percent), multi-infarct patients (22.2 percent), and TBI patients (11.8 percent). None of the normals was classified as left hemisphere. However seven were classified as right hemisphere, five as TBI, and four as multi-infarct. One left hemisphere patient was classified as normal, seven as multi-infarct, two as right hemisphere, and one as TBI. Right hemisphere patients were more often classified as normal or multi-infarct than as right hemisphere. Twice as many multi-infarct patients were classified as left hemisphere than were classified as bilateral multi-infarct. TBI patients were more often classified as normal, right hemisphere, or multi-infarct than they were as TBI.

Table 7. Discriminant function analysis classification of normals and left hemisphere, right hemisphere, bilateral multi-infarct, and bilateral traumatic brain injured patients.

ACTUAL GROUP	PREDICTED GROUP MEMBERSHIP				
	Normal	Left	Right	MI	TBI
Normal (N = 40)					
Number of Cases	24	0	7	4	5
Percent of Cases	60.0	0	17.5	10.0	12.5
Left Hemisphere (N = 40)					
Number of Cases	1	29	2	7	1
Percent of Cases	2.5	72.5	5.0	17.5	2.5
Right Hemisphere (N = 40)					
Number of Cases	12	3	10	11	4
Percent of Cases	30.0	7.5	25.0	27.5	10.0
Multi-Infarct (N = 18)					
Number of Cases	1	8	2	4	3
Percent of Cases	5.6	44.4	11.1	22.2	16.7
Traumatic Brain Injury (N = 17)					
Number of Cases	7	1	3	4	2
Percent of Cases	41.2	5.9	17.6	23.5	11.8

Percent of all cases classified correctly = 44.5

DISCUSSION

Our results indicate that the Word Fluency Measure is somewhat sensitive to the presence of brain damage. Each of our brain damaged groups produced significantly fewer words than our normal group. However, when the bilateral group was divided by cause of brain damage, traumatic brain injured patients did not differ significantly from normals. The sensitivity of the Word Fluency Measure to brain damage in individual patients is underwhelming. A discriminant function analysis classified 71.9 percent of the cases correctly. Nine of 40 normals were classified as brain damaged, and 36 of 120 brain damaged patients were classified as normal.

The Word Fluency Measure's ability to differentiate among groups of brain damaged patients is equally poor. Approximately 48 percent of all cases were classified correctly when bilateral patients with different etiologies were combined. When bilateral patients were separated into multi-infarct and traumatic brain injury groups, correct classification dropped to approximately 45 percent.

A left hemisphere infarct significantly reduces the number of words a patient will produce on a Word Fluency Measure. Patients with left hemisphere infarcts and patients with bilateral multi-infarcts produced significantly fewer words than all other groups, including patients with bilateral traumatic brain injury.

Perhaps modifying the measure would improve its discriminating power. However, a careful reading of Borkowski, Benton, and Spreen's (1967) results indicates that this is unlikely. Their comparison of performance on letters of different difficulty indicated that at least half of their brain damaged sample performed above the 16th percentile for normals on each combination of letters. Our analysis of performance on each individual letter did not improve classification above that obtained with total scores. Exploration of different strategies in producing words (Adamovich and Henderson, 1984) may be more fruitful. However, Collins et al. (1984) found that this type of qualitative analysis did not differentiate among different types of aphasic patients.

Word Fluency Measure performance may be influenced by the intrahemispheric location of the lesion. Some (Perret, 1974; Ramier and Hecaen, 1970) report that patients with frontal lesions perform more poorly than patients with retrorolandic lesions. Others (Miceli et al., 1981; Newcombe, 1969), however, have found no intrahemispheric influences on performance. Darley (1979) observed that we do not have a single mesure that differentiates among patients who display different neuropathologies of speech and language. Our results indicate that the Word Fluency Measure we employed is not a likely candidate.

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DISCUSSION

C: Two years ago at ASHA we reviewed a number of qualitative analyses that we performed on three word fluency tasks. One was words beginning with the letter "S," another was animals from the Boston, and the third was foods. We found that the letter task was the least useful in determining the absence or presence of brain damage. It was an artificial measure of the way we organize information. The literature suggests that information is organized according to categories and subcategories and using letters doesn't provide any opportunity for a subject to use a strategy to produce rsponses. We found that the measure of animals and foods lent itself readily to superordinant and subcategorization of responses. Consequently, we found that one of the two differences betwen brain damaged and normal groups was the size of the subcategory responses within the measure. That is, on the food items, normal subjects would typically provide five, six, or seven organized responses--breakfas foods, or sandwiches--and then move over into another category, whereas the brain damaged subjects would produce one or two items within a subcategory, and switch over to another subcategory. The second behavior that appeared to discriminate was the degree of subcategory recurrence. That is, the brain damaged subjects would go from fruits to vegetables, back to fruits, then to sandwiches, or lunch meats, then back to vegetables, then back to fruits. They were unable to exhaust the category, leave it, and go on to something else. Consequently, we found what we called a measure of word fluency efficiency. I suspect that your discriminant function analysis would have provided stronger differences among groups if you used a word fluency task that, in fact, represented the way we actually organize information. I don't think we organize information according to letters of the alphabet. Thus, letters impose an artificial organization on the subjects, and because it's artificial, I don't think we can make any distinction between normal and abnormal.

Q: Did the different tasks influence total scores?

A: We found that they did in our study. The number of responses decreased as we went from foods, to animals, to words beginning with "S." The reason we used foods was based on previous work by others that suggested that foods is a category developed on the basis of experience. Most of us have had a lot of experience with food. Animals is a category developed on the basis of education. Not all of us have been to Africa to see African animals, but we can organize those animals into a category on the basis of our education level. The "S" category represented the most abstract of the three. We found our subjects did better in experiential-based categorizations than in the abstract. We saw more items for foods, a slightly smaller number of items for animals, and "S" was the poorest of all in all of our groups. So, I suspect that your numbers were influenced by the category that you used. Perhaps using tasks that more accurately represent semantic organization would change those numbers considerably.

Q: When you recorded responses, did you take any word that the subjects said as long as it began with the specified letter, or did you put limits on what you would accept?

A: We accepted anything that was a real word beginning with the specified letter.

Q: What you entered into the discriminant function analysis was the total words produced for all four letters?

A: Right. We ran analyses on individual letters. These did not discriminate any better than the total score.

Q: I have a comment and a question. First, I wonder when subjects change categories if they are showing an inability to attend to the task, and you are measuring an attention deficit rather than an ability to categorize. Now my question. Did you consider controlling for age in your normal group? Was your head injury group younger?

A: Yes. Initially, the bilateral group was significantly younger than all other groups. That was because of the young head injured patients. When we separated the bilateral group into multi-infarct and head injured, the multi-infarct group did not differ from the normals, the rights, or the lefts in age, but the head injured were significantly younger than all other groups.

Q: Okay. I think there is some information available that indicates older normals have more problems with word fluency tasks than younger normals. Do you think that you may have seen a difference between normals and head injured if you had compared younger normals?

A: Maybe. Word Fluency performance correlates significantly with education but not age in adults. A lot depends upon where you get your normals. When Peg Lemme and I developed Word Fluency norms, we were getting a nice tailing off from about 55 on out to 90, until we went into a Methodist retirement home where everybody did crossword puzzles. Doing research on aging makes investigators weep. There are so many influences.

Q: Would you address the influence of severity of deficits and how that influences within-group variations?

A: There was a range of performance within all groups. The normals did not have what we considered "deficits," but they showed a range of performance. Damage in the left hemisphere reduces Word Fluency performance, and that performance correlates significantly with other measures, for example the PICA and the Token Test in aphasic patients. I do not know how Word Fluency performance relates to the severity of other deficits--for example, the nonaphasic "deficits" seen in right hemisphere brain damaged patients and head injured patients. I would guess that several things created the range of performance we saw in all groups--education, perhaps intelligence, fondness for and use of language, location and extent of brain damage, ability to focus and sustain attention, etc. Probably all of these interact, and they interact differently in different groups.