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Closed- and Open-Class Lexical Access in Agrammatic and Fluent Aphasics

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Bradley, Garrett, and Zurif (Bradley, *Computational distinctions of vocabulary type*. Unpublished doctoral dissertation, MIT Press; Cambridge, MA, 1978; *Biological studies of mental processes*, MIT Press, Cambridge, MA, 1980) have suggested that closed-class word access is normally mediated by a different route than the open-class one, and that the loss of this closed-class route might account for agrammatism. However, in an earlier study (Gordon & Caramazza, *Brain and Language*, **15**, 143–160, 1982) we were not able to confirm a meaningful difference between closed- and open-class word frequency responsiveness of the type Bradley (unpublished dissertation, 1978) had seemed to find in normal subjects. We have now done a direct comparison of closed-class frequency sensitivity in agrammatic and nonagrammatic aphasics, to directly test Bradley and colleagues' hypotheses and to avoid some of the experimental problems with between-class frequency comparisons. We find that closed-class words behave similarly whether or not the subject is agrammatic. Therefore, the differences between agrammatic and nonagrammatic aphasics must arise at a deeper level (or levels) of lexical processing than the one probed by the frequency sensitivity effect.

Bradley, Garrett, and Zurif (Bradley, 1978; Bradley et al., 1980; Garrett, 1979; Zurif, 1980) have suggested that there is normally a specialized

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brain system that mediates the lexical access and retrieval of the elements of grammatical structure in the language. They have further suggested that the agrammatic speech comprehension and production in Broca's aphasia is a consequence of damage to this specialized system. Their empirical motivation for these hypotheses has come from their demonstration of differences in the processing of free-standing grammatical morphemes ("open-class" words). One important series of experiments appeared to show differences between the frequency sensitivity of the two classes of words in a standard lexical decision task: with normal subjects, the closed-class words seemed to show virtually none of the expected frequency effect that was well demonstrated by the open-class words (Bradley, 1978; Bradley et al., 1980). This was also true for five hospitalized control subjects (Bradley, 1978), and for two patients with Wernicke's aphasia (Bradley et al., 1980). However, in striking contrast, the closed-class words *did* show a frequency effect with five agrammatic Brocas, an effect comparable to that of the open-class words (Bradley, 1978).

However, in a series of experiments patterned after Bradley's (1978) lexical decision tasks exploring frequency sensitivity, we did not find a significant difference between the behavior of the two word classes with normal subjects (Gordon & Caramazza, 1982). Nevertheless, this between-class comparison invites unavoidable experimental problems because of the limited numbers of closed-class items and because of the limited overlap between the two classes, among other reasons. Comparing closed-class frequency sensitivities directly between agrammatic and nonagrammatic aphasics obviates many of these problems. Bradley et al. (1980) report a tentative test, with their results supporting a difference. We have now employed what we consider a somewhat more sensitive paradigm (Experiment 2 from Gordon & Caramazza, 1982) with a group of 10 language-impaired patients to subject Bradley and colleagues' (1980) hypotheses and experimental evidence to this more definitive test.

SUBJECTS

Table 1 is a summary of each patient's functional impairments and diagnosis. We do not regard "agrammatism" as synonymous with "Broca's aphasia". "Agrammatism" was diagnosed on the basis of both the following criteria: frequent omissions of function words and of bound grammatical morphemes in spontaneous speech, and stereotypic use of both bound and free grammatical morphemes (see, for example, Caramazza et al., 1981). All of these patients also have asyntactic comprehension (Caramazza et al., 1981). Patients who meet the complete research criteria for agrammatism are not common; the patients we present here have been gradually selected by two separate groups of investigators in this geographic area. (See the references cited in Table 1.) We have distinguished, for this paper, a separate "nonfluent, aphasic" group; both of these patients have such limited speech output that it is impossible to determine if their speech production is grammatic or not. One of these patients (E.K.) writes agrammatically, however.

All of these patients have been, or are undergoing, extensive investigations of their language and related disorders. (See the references in Table 1.)

MATERIALS AND METHODS

The materials and design of this experiment with the language-impaired patients were identical to those of our previously-described Experiment 2 with normal subjects (Gordon & Caramazza, 1982). Briefly, we tested 139 closed-class words and 138 open-class words, spanning a wide frequency range. Most of these words had also been used by Bradley (1978). Phonologically- and orthographically-legal nonwords were created to match the words in length, number of syllables, and initial letter or letter combination.

Apparatus. Stimuli were presented on a high-resolution video screen, with presentation and timing controlled by a microcomputer. One of the agrammatic patients (B.L.) was tested using lower-case letters with a PET microcomputer system; all others were shown upper-case stimuli via an Apple system modified for experimental use. Items subtended no more than 3.0° horizontally and 0.5° vertically at a comfortable reading distance.

Procedure. Subjects were instructed orally to identify the letter strings as either words or nonwords. If they thought the string was a word, they were to press a microswitch held in their left hand as rapidly as possible without making more than occasional errors. (The left hand was used for response, as in Bradley, 1978, because several of the patients had right-sided hemipareses.) If they did not think the item was a word, no response was required. This single response technique had been used in two of the experiments with normal subjects we reported earlier (Gordon & Caramazza, 1982), and directly compared with the results of a third using the standard two-response, "yes/no" technique (Gordon & Caramazza, 1982; Gordon, 1983). Responses made with the go/no-go technique appear to reflect the word frequency effect in lexical decision just as the standard technique does, with the benefits of significantly smaller reaction time variances and fewer errors (Gordon & Caramazza, 1982; Gordon, 1983). It was used with the patient group in order to gain the highest possible experimental resolution.

Each trial was initiated by the experimenter, who checked if the subject was ready before starting. The screen then displayed a "*" in the center for visual fixation for 0.5 sec, followed by a blank period of 0.25 sec, followed by the letter string in the center of the screen. The string was displayed for 3.0 sec, regardless of the response. (In our previous experiments, the normal subjects had initiated each trial themselves by foot pedal, and a 1.5-sec display period had been enough. Bradley (1978) also presented items for a fixed time; she varied the display period depending upon each subject's response speed.)

Data analysis. The first 29 trials of the first block and the first 3 trials of the second were discarded as practice. Log frequencies per million were calculated using the Kucera and Francis (1967) count. For this analysis, a "conservative" assignment of item frequency based on the inclusion of all regular derivational forms (forms that did not change word meaning) was used. These frequency assignments were usually identical to Bradley's (1978).

In our previous experiments (Gordon & Caramazza, 1982), the closed-class word "nor" had not unexpectedly shown somewhat slower responses than other words of comparable frequency; because of this explicably anomalous behavior, its reaction times were not analyzed in this experiment. We also excluded outliers using a per-subject reaction time criterion as Bradley (1978) had done; items with reaction times greater (or less) than two

TABLE 1
PATIENT DESCRIPTIONS

Patient type	Initials	Age at test	Education (years)	Time since event (years)	Etiology	Localization (CT scan)	Functional description
Agrammatic Brocas	B.L.[a]	58	9	6	Infarct	Lucency on L[f] in Broca's area, temporal, and inferior parietal regions.	Agrammatic production, asyntactic comprehension, and deep dyslexia
	V.S.[b]	57	12	9	Infarct	Probable partial involvement Broca's area; definite involvement L posterior temporal and L inferior parietal regions	Agrammatic production, asyntactic comprehension, and deep dyslexia
	B.D.[c]	63	12	7	Infarct	One region of lucency on L affecting Broca's area, caudate and putamen; other in L medial occipital lobe, and possibly in splenium of corpus callosum	Mildly agrammatic production, asyntactic comprehension
	F.M.	39	12	0.5	Infarct	Lucency on L in Broca's area, superior portion of temporal lobe, inferior parietal lobe, and lateral basal ganglia, with left frontal cortial atrophy	Agrammatic production, asyntactic comprehension, and deep dyslexia
Nonfluent aphasics	A.P.	64	14	6	Infarct	Lucency on L affecting Broca's area, temporal and inferior parietal lobes	Limited, anarthric production, normal comprehension
	E.K.	55	7	1.5	Infarct	No definite involvement of Broca's area; lucency of L	No significant speech output, asyntactic

Fluent non-agrammatics	J.S.[d]	48	14	2.5	Infarct	Lucency on L of posterior superior temporal lobe and inferior parietal region	Fluent paraphasic speech, impaired auditory comprehension with relatively intact reading comprehension
	V.O'F.[e]	62	9	6	Infarct	Large area of lucency on L affecting Broca's area and temporal and inferior parietal lobes	Fluent production with word finding difficulties, relatively intact comprehension
	P.E.	53	15	1.5	Infarct	Cortical atrophy possibly involving Broca's area, definitely affecting superior L temporal lobe, with lucency in L periventricular white matter and dilatation of anterior horn of L lateral ventricle	Fluent production with word finding difficulties, relatively intact comprehension
	D.W.	45	12	3	Infarct	(Not available)	Fluent output with occassional paraphasias, disproportionate inability to repeat, relatively good comprehension

Other descriptions of some of these patients can be found in the following sources:
[a] Caramazza et al., 1981; Saffran et al., 1980; Schwartz et al., 1980.
[b] Saffran et al., 1980; Schwartz et al., 1980.
[c] Caramazza et al., 1981.
[d] Caramazza et al., 1983.
[e] Caramazza et al., 1981.
[f] L = left.

standard deviations from that subject's mean were eliminated from further analysis. All other words with valid reaction time data were included in the analysis.

Reaction time data were analyzed directly, and were also log transformed to minimize the dependency of variance on latency and to lessen the effects of differing baseline reaction times between the different subjects (Myers, 1972; Winer, 1971). An additional adjustment for individual reaction time differences was tested: using the log-transformed data, each subject's mean reaction time on the very highest frequency words (frequencies greater than 399/million) was used to scale his or her individual reaction times to a reference point which was common to all subjects. This transformation smoothed the plots of the groups' reaction-time data, but the pattern of correlation coefficients was not appreciably affected.

RESULTS

Table 2 summarizes each patient's errors. Table 3 presents each word class' frequency sensitivity for the patient groups in terms of the correlation of reaction time with the log of the frequencies, as in Bradley (1978) and Gordon and Caramazza (1982). Table 4 gives the correlations using logarithmically transformed reaction times.

Comparisons of Agrammatic with Nonagrammatic Patients

Since the principal issue is whether closed-class performance for the agrammatics differs from that of the nonagrammatics, we can directly compare correlation coefficients, and ignore factors such as word length which are almost exactly balanced between the patient groups. Bradley's (1978) agrammatics showed an appreciable frequency effect for the closed-

TABLE 2
PATIENT ERROR RATES

		False negatives[a]		
		Closed class (%)	Open class (%)	False positives (%)
Agrammatic	B.L.	11	4	6
Brocas	V.S.	1	0	6
	B.D.	2	1	19
	F.M.	11	1	7
Mean		6.5	1.7	9.7
Nonfluent	A.P.	1	0	2
aphasics	E.K.	10	4	9
Mean		5.2	1.9	5.4
Fluent	J.S.	3	2	11
nonagrammatics	V.O'F.	8	2	9
	P.E.	5	4	10
	D.W.	5	8	2
Mean		5.3	3.6	8.6

[a] No attempt was made to correct for vocabulary differences.

TABLE 3
FREQUENCY SENSITIVITIES—UNTRANSFORMED REACTION TIMES

	Overall	Log frequency range	
		≤2.5	>2.6
Closed-class words			
Agrammatic Brocas ($n = 4$)	−.20	−.21 (−.20)[a] ($df = 143$, $p = .008$)	−.10 (−.04) ($df = 315$, $p = .26$)
	[$z = .97$, $p > .30$][b]	[$z = .00$, $p > .99$]	[$z = .00$, $p > .99$]
Fluent nonagrammatics ($n = 4$)	−.31	−.21 (−.13) ($df = 150$, $p = .05$)	−.10 (+.02) ($df = 317$, $p = .34$)
	[$z = .65$, $p > .51$]	[$z = 1.0$, $p > .31$]	[$z = -.58$, $p > .55$]
Nonfluent aphasics ($n = 2$)	−.38	−.41 (−.31) ($df = 73$, $p = .004$)	−.01 (−.01) ($df = 154$, $p = .43$)
Open-class words			
Agrammatic Brocas ($n = 4$)	−.15	−.10 (−.09) ($df = 287$, $p = .07$)	−.06 (−.06) ($df = 178$, $p = .21$)
	[$z = .01$, $p > .99$]	[$z = .56$, $p > .55$]	[$z = .01$, $p > .99$]
Fluent nonagrammatics ($n = 4$)	−.16	−.19 (−.16) ($df = 270$, $p = .004$)	−.08 (−.06) ($df = 173$, $p = .22$)
	[$z = 1.0$, $p > .31$]	[$z = .01$, $p > .99$]	[$z = 1.0$, $p > .31$]
Nonfluent aphasics ($n = 2$)	−.28	−.20 (−.19) ($df = 136$, $p = .01$)	−.29 (−.18) ($df = 86$, $p = .05$)

[a] Items in parentheses are correlations with length partialed out and their corresponding significance levels.

[b] Significance tests are over the total number of words in each condition, for the unpartialed correlation coefficients; all are two tailed. Comparisons between the agrammatic Brocas and the nonfluent aphasics (not shown) were also not significant.

class words when measured over their entire range ($r = -0.38$), whereas normal matched controls did not ($r = +0.05$). Our patients showed no evidence of such a dissociation, with either nontransformed or log-transformed reaction-time analyses (see Tables 3 and 4): for the agrammatics, $r = -0.20$ (untransformed, as are all the following examples); for the fluent nonagrammatics, $r = -0.31$; for the nonfluent group with indeterminate grammatical ability, $r = -0.38$. None of the numerical differences in correlation coefficients between these groups is significant; their trend is in fact the opposite of the one Bradley's (1978) hypotheses would predict. Nor is there any evidence from each patient's closed-class performance of any meaningful heterogenity that might have been obscured by the categorical groupings: for the agrammatics, the closed-class frequency correlations are -0.32, -0.25, -0.20, and -0.40; for the nonfluent, indeterminate patients, -0.50, and -0.37; for the fluent nonagrammatics,

TABLE 4

FREQUENCY SENSITIVITIES—LOG-TRANSFORMED REACTION TIMES

		Log frequency range	
	Overall	≤2.5	>2.6
Closed-class words			
Agrammatic Brocas ($n=4$)	−.22	−.20 (−.18)[a] ($df = 143$, $p = .016$)	−.11 (−.05) ($df = 315$, $p = .17$)
	[$z = .71$, $p > .47$][b]	[$z = .14$, $p > .88$]	[$z = -.01$, $p > .99$]
Fluent nonagrammatics ($n = 4$)	−.30	−.23 (−.16) ($df = 150$, $p = .03$)	−.10 (+.02) ($df = 317$, $p = .36$)
	[$z = 1.1$, $p > .27$]	[$z = 1.3$, $p > .19$]	[$z = -.39$, $p > .69$]
Nonfluent aphasics ($n=2$)	−.42	−.47 (−.35) ($df = 73$, $p = .001$)	−.04 (−.02) ($df = 154$, $p = .41$)
Open-class words			
Agrammatic Brocas ($n = 4$)	−.17	−.13 (−.11) ($df = 287$, $p = .03$)	−.08 (−.06) ($df = 178$, $p = .20$)
	[$z = .00$, $p > .99$]	[$z = .25$, $p > .80$]	[$z = -.01$, $p > .99$]
Fluent nonagrammatics ($n=4$)	−.17	−.17 (−.15) ($df = 270$, $p = .006$)	−.06 (−.03) ($df = 173$, $p = .33$)
	[$z = 1.4$, $p > .16$]	[$z = .64$, $p > .51$]	[$z = 1.0$, $p > .31$]
Nonfluent aphasics ($n = 2$)	−.33	−.27 (−.26) ($df = 136$, $p = .001$)	−.27 (−.17) ($df = 86$, $p = .05$)

[a] Items in parentheses are correlations with length partialed out and their corresponding significance levels.

[b] Significance tests are over the total number of words in each condition, for the unpartialed correlation coefficients; all are two tailed. Comparisons between the agrammatic Brocas and the nonfluent aphasics (not shown) were also not significant.

−0.34, −0.24, −0.45, and −0.29. (The ordering of these correlations corresponds to the ordering of patients in Table 1.)

Our previous study of normal subjects showed that reaction time is not a linear function of log frequency over the highest frequency ranges; for both word classes, reaction time appeared to reach a floor or saturation with frequencies above 316–399/million (log frequencies of 2.5–2.6) (Gordon & Caramazza, 1982). This nonlinearity also appeared to be true of the patients' reaction-time functions, based on visual inspection of the individual and combined results; it was not statistically significant with the mean reaction-time data, but reached significance with the individual data: with untransformed reaction time, and both classes considered together, $F(175, 2354) = 1.4, p = .001$; with the transformed, scaled reaction times, with either class considered separately ($F(107, 1136) = 2.1, p < .0001$ for the open-class; $F(101, 1183) = 2.0, p < .0001$ for the closed-class). (In all cases, we used the tests for nonlinearity described by Nie et al., 1975, pp. 259–261.) Therefore, the data was also analyzed separately over lower and upper frequency segments (see Gordon & Caramazza, 1982). As can be seen in Tables 3 and 4, there is again no pattern consistent with Bradley's (1978) hypotheses predicting a difference between agrammatic and nonagrammatic aphasia.

Therefore, there is no evidence from this lexical decision task of a distinction between agrammatics' and nonagrammatics' closed-class frequency sensitivities.

Closed- vs. Open-Class Frequency Sensitivities

The data from the four fluent, nonagrammatic patients also clearly shows a closed-class frequency effect. This is true over the entire frequency range, as well as over the more-appropriately analyzed lower half (away from the region of the reaction-time floor). More tellingly, a significant frequency effect remains even when the confounding influence of length is partialed out (see Tables 3 and 4). The closed-class' frequency sensitivity is also comparable to the open class' for these patients (although because of different frequency spectra, the closed-class' frequency sensitivity is not strictly commensurate with the open classes'). The data from our four patients without syntactic impairment lends support to the conclusion we drew from a larger, normal, population: there is no evidence for a difference between open- and closed-class frequency sensitivities in word lexical decision.

DISCUSSION

The results we have reported refute a very specific claim about the underlying basis for agrammatism; that is, that agrammatism results from a disruption of a frequency-insensitive, closed-class access system. We have *not* found any evidence that closed- and open-class words behave differently as a function of frequency in either normal subjects (Gordon & Caramazza, 1982) or in the groups of aphasics reported here.

However, we wish to emphasize that our noncorroborative results do not mean that there are no processing differences between closed- and open-class words, nor do they necessarily mean that a deficit in processing closed-class items does not occur in agrammatism. There is compelling evidence from both normal and aphasic populations that function words behave differently from the major lexical items. To cite just two examples: Bradley (1978; Bradley et al., 1980) has shown differences between nonword decisions depending upon whether the nonword has a closed- or an open-class word as its initial segment. And agrammatics provide one of the most striking examples of the closed/open-class dichotomy, as this group is defined in terms of a differential ability to produce these items. Consequently, we must assume that there is some level or levels where the two classes of items have different representations, or use different processes, and are therefore susceptible to different experimental influences and to selective disruption.

This experiment and our previous ones on open/closed-class frequency sensitivity (Gordon & Caramazza, 1982) do help highlight some critical experimental problems with investigations of the open/closed-class distinction in particular, and with the general question of how syntax is represented in the brain. Among these problems or questions are those of assigning patients to the agrammatic versus nonagrammatic groups (simply trusting a clinical diagnosis of Broca's aphasia is clearly not sufficient); choice of the word stimuli to include only those with truly syntactic roles; and recognition of just what aspects of lexical processing are being tapped by our experimental tools and dependent measures.

These and other factors may partially explain why we could not replicate portions of Bradley's (1978; Bradley et al., 1980) work. The next steps in the experimental study of agrammatism and syntactic processing will have to directly confront these issues.

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