The Effects of Focal Brain Damage on Sentence Processing: an examination of the neurological organization of a mental module

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Abstract

The effects of prior semantic context upon lexical access during sentence processing were examined for three groups of subjects: nonfluent agrammatic (Broca's) aphasic patients; fluent (Wernicke's) aphasic patients; and neurologically intact control patients. Subjects were asked to comprehend auditorily presented, structurally simple sentences containing ambiguities, which were in a context strongly biased toward just one interpretation of that ambiguity. Whie listening to each sentence, subjects also had to perform a lexical decision task upon a visually presented letter string. For the fluent Wernicke's patients, as fr the controls, lexical decisions for visual words related to each of the meanings of the ambiguity were facilitated. By contrast, agrammatic Broca's patients showed significant facilitation only for visual words related to the a priori most frequent interpretation of the ambiguity. On the basis of these data, we suggest that normal form-based word retrieval process are crucially reliant upon the cortical tissue implicated in agrammatism, but that even the focal brain damage yielding agrammatism does not destory the normally encapsulated form of word access. That is, we propose that in agrammatism, the modularity of a word access during sentence conprehension is rendered less effecient but not lost. Additionally, we consider a number of broader issues involved in the use of pathological material to infer characteristics of the neurological organization of cognitive architecture.

Introduction

A fundamental issue in the study of the human language comprehension system concerns whether that system is highly modular, that is, comprised of a set of autonomous, informationally encapsulated subsystems, or whether it consists of a set of maximally interactive subsystems. The past decade has witnessed a large number of theoretical and empirical approaches to this issue (e.g., Tyler and Marslen-Wilson, 1982; Swinney, 1982; 1984), and a re-emergence of the modularity hypothesis in a more comprehensive and explicit form (Fodor, 1983). Interestingly, while much of the earliest evidence taken as support for the modularity thesis came from neuropsychological observation concerning brain localization of functional domains of behavior (the best known example being that of language), neuropsychological analyses have yet to provide a major source of evidence either for or against the more recent fine-grained theories of modularity. The work reported here seeks to redress this situation.

In what follows, we provide a characterization of sentence comprehension limitations in aphasia that turns on aspects of the general issue of modularity and, more specifically, on the issue of autonomy of a putative language processing subsystem-that serving lexical access (that process whereby the acoustic or graphemic 'form' of a word contacts its mental representation, such that information in that representation is made available for further processing). We examine the possibility that a disruption of this access process underlies comprehension deficits found in a specific form of aphasia, agrammatic Broca's aphasia. Our goals are both to establish details of this processing disruption and also to examine issues concerning modularity in the language processing system using leverage provided by evidence from focal brain damage. Below, we first provide background detail which characterizes the normal operation of the lexical access process during sentence comprehension. Following this, we provide an account of how the issue of modularity bears on our understanding of aphasia, and, in particular, how our understanding of the comprehension deficit involved in agrammatic aphasia relates to issues of lexical access.

Normal Lexical Access

For both historical and practical reasons, studies of normal lexical processing have provided the focus for much of the experimental examination of claims about autonomy (modularity) in the language processing system. The general aim of this work has been to determine whether any particular process-here we focus on lexical access-is, at any point, autonomous and independent of the influence of `contextual' information, or contrastively, whether this process is penetrated or constrained by contextual information.

A great deal of the work in this field has turned on examinations of the processing of polysemous words during sentence comprehension. Such words provide an ideal target for the examination of the effects of context upon lexical access, in that the effect of prior contextual information upon the processing of each meaning of the ambiguity can be independently examined. (See, in particular, reviews of much of this work by Seidenberg, Tanenhaus, Leiman, and Bienkowski 1982; Simpson 1984; Swinney 1981). In this work, much of the critical evidence has come through the use of on-line processing measures, measures of processing which are taken temporally close to the event of interest during ongoing comprehension. One of these, cross modal lexical priming (CMLP), uses the results of semantic priming (e.g., Meyer, Schvaneveldt, and Ruddy 1975) to reveal the activation of specific word meanings in a sentence during the comprehension of that sentence (Swinney, Onifer, Prather and Hirshkowitz 1979).

Using this technique, Onifer and Swinney (1981) presented subjects with sentences containing biasing contexts and ambiguous words, and measured the activation of the various meanings for each ambiguity immediately after it had occurred in the sentence. In this study, sentential contexts were used that biased the ambiguities either toward the a priori most frequent (primary) interpretation of the ambiguity or toward the least frequent (secondary) interpretation of the ambiguity. Thus, for example, subjects heard the sentence:

> "The dinner guests enjoyed the river bass, although one guest did get a scale* caught in his throat."

The subjects were required to make lexical decisions to letter strings that were semantically related to the primary and secondary meaning of "scale," such as "WEIGHT" and "FISH," which appeared on a visual display monitor immediately after "scale" was heard (as indicated by '*').

The Onifer and Swinney (1981) results demonstrated that immediately after the ambiguity was heard there was priming for lexical decisions to visual words related to both the primary and secondary interpretations of the ambiguous word "scale" (both FISH and WEIGHT) compared to their controls, regardless of the prior contextual bias provided in the sentence. Thus, even when the secondary meaning of the ambiguity was inappropriate given the context, that meaning was at least momentarily accessed during sentence comprehension. Importantly, this same experiment demonstrated that, at a point 1.5 seconds after the ambiguous word was heard in the sentence, only the contextually relevant interpretation of the ambiguity was still primed. Thus, the CMLP technique reveals that, initially, both meanings of an ambiguity are activated, but that only the contextually appropriate interpretation is maintained later in the sentence. This fact comports happily with our knowledge that listeners eventually understand (and usually only become aware of) the contextually appropriate interpretations of lexical ambiguities during normal discourse comprehension.'

Taken in their strongest interpretation, these results, and a growing body of research on this issue utilizing other true on-line processing techniques (see Swinney 1981 and Seidenberg and Tanenhaus, 1982, for detailed reviews), lead to three general conclusions: First, that lexical access during normal sentence comprehension is an autonomous process, driven solely by the form (phonological shape) of the word, independent of prior context; second, that normal retrieval of information (e.g., meanings) for any particular form (word) during normal access is exhaustive - all meanings are accessed, independently of prior context; and third, that contextual information has its effect upon lexical processing only following access during normal sentence comprehension. In effect, it appears that the normal sentence processing system provides a fully (exhaustively) elaborated lexical data base for subsequent sentential processes (such as structural, semantic, and pragmatic routines) to operate on. (But, see Tyler & Marslen-Wilson 1982, for a different stance.)

Lexical Access in Aphasia

In the context of these findings it might reasonably be supposed that aphasic sentence comprehension limitations are at least partly a consequence of a failure to provide a normally elaborated lexical data base upon which to carry out these further analyses. And indeed, the lexical system has already been implicated, in varying degrees, in the linguistic limitation seen in agrammatic Broca's aphasia, a syndrome that involves a relative omission of function words and a restriction to simple syntactic forms in speech and that also often involves deficits in the comprehension of complex constructions. (See the methods section below, and M.-L. Kean 1985, for more detailed discussions of agrammatism.) Specifically, Bradley, Garrett, and Zurif (1980) and Rosenberg, Zurif, Brownell, Garrett, and Bradley (1985) have characterized the agrammatics' failure to perform normal syntactic analysis as the consequence of a disruption to a normally unconscious and automatic system that accesses the closed class lexicon (vocabulary from the `minor' grammatical classes, which form, roughly speaking, the 'function' words of our language). Further, both sets of investigators have reported that this disruption is observed only in agrammatic aphasia; in both studies `fluent' aphasic patients, who presented word finding difficulties in the context of superficially grammatical speech, did not show this disruption.

From our present perspective this is equivalent to viewing the disruption in agrammatism (but not in fluent aphasia), as one that results in a failure to provide the relevant (and fully elaborated) lexical information at the right time in the processing sequence. This is suggested also by studies by Milberg and Blumstein (1981) and Blumstein, Milberg, and Shrier (1983). These investigators have demonstrated disruptions in a form of "automatic" processing involving lexical access in a word-pair priming task in Broca's aphasics, but again, not in fluent aphasic patients.

In all, there exists evidence arguing for disruption to normal lexical processing in agrammatic aphasics. However, such evidence only indirectly speaks to the hypothesis under consideration here: namely, that a module-specific disruption to lexical access is implicated in the real-time sentence processing routines of agrammatic aphasics. Further, even if this hypothesis is supported, a question remains concerning the nature of this lexical processing disruption. Will the disruption be of a form such that the modularity (autonomy) of access is destroyed? That is, will agrammatic patients compute only contextually relevant word meanings in a sentence? Or, will the disruption be shown to preserve the functional architecture underlying modularity and simply render the affected module less efficient in some fashion? Finally, whichever form the disruption takes, will it be a disruption that holds across aphasias, or will it be specific to agrammatic Broca's aphasia, as predicted? While both fluent (Wernicke's) aphasic patients and agrammatic Broca's aphasic patients have some superficially similar comprehension limitations, it seems that a disruption to early automatic aspects of word recognition appears only in the latter group (Bradley et al. 1980; Milberg and Blumstein 1981; Rosenberg et al. 1985). Accordingly, will these two forms of aphasia be shown to bracket the operation of a modular lexical access device?

We address these questions utilizing the CMLP technique to examine the effects of contextual information upon lexical access during sentence comprehension in agrammatic Broca's aphasics, Wernicke's aphasics, and a population of age-matched, neurologically intact control subjects.

Results

The sentences used in this study were structurally simple. Thus, it was not surprising to observe that all of the subjects provided adequate paraphrases on those trials on which comprehension was assessed. Accordingly, the reaction time data that follow are to be viewed as arising in the context of sentence comprehension.

The data for each of the three subject groups were submitted to independent analyses. It was discovered post hoc that the four visual-word test conditions had not been entirely equally distributed across the four presentation lists and that the 24 experimental sentences had not been divided entirely equally into conditions of bias toward the most likely and least likely interpretation of the ambiguity. To correct for this in the analysis, a total of three sentences were dropped from all analyses (in one case due to inappropriate bias assignment and in the other two due to inappropriate visual word assignment).

Although the major analyses involved evaluation of reaction time data, an initial analysis of the error data was performed to determine whether there were any obvious speed/accuracy tradeoffs to be concerned with in the data (such tradeoffs are often the source of data interpretation problems with clinical populations), as well as to determine whether or not the three subject groups were equivalent in such matters as practice effects and task understanding. The mean number of errors for each of the experimental conditions are displayed in Table 1, separately for the neurologically intact control subjects, the Wernicke's aphasics, and the agrammatic Broca's aphasics. As can be seen by inspection, there were no significant differences in number of errors for any experimental condition either between subject groups or within any groups' data, with the single exception of the replication condition for the Wernicke's aphasics.

Unlike the other subject groups, the Wernicke's aphasics clearly demonstrate a significantly higher number of errors in their initial experience with the experimental task (Replication 1) than they do in their subsequent experience with the task (Replication 2), or than either of the other subject groups do in any of their experiences with the task. Clearly this reflects an increased ease of

Table 1

MEAN NUMBER OF ERRORS

A. Neurologically Intact Control Subjects

	VISUAL PROBE WORDS			
	Primary Interpretation		Secondary Interpretation	
	related	control	related	control
CONTEXTUAL BIAS				
Replication 1				
primary interpretation	2	1	2	2
secondary interpretation	0	1	0	0
Replication 2				
primary interpretation	1	2	0	0
secondary interpretation	0	1	0	0

B. Wernicke's Aphasics

	VISUAL PROBE WORDS			
	Primary Interpretation		Secondary Interpretation	
	related	control	related	control
CONTEXTUAL BIAS				
Replication 1				
primary interpretation	5	7	7	4
secondary interpretation	6	5	5	3
Replication 2				
primary interpretation	2	2	0	0
secondary interpretation	0	2	2	2

C. Broca's Aphasics

	VISUAL PROBE WORDS			
	Primary Interpretation		Secondary Interpretation	
	related	control	related	control
CONTEXTUAL BIAS				
Replication 1				
primary interpretation	2	2	0	2
secondary interpretation	1	0	0	0
Replication 2				
primary interpretation	0	1	1	0
secondary interpretation	2	1	0	0

dealing with the task. In: any case, due to the well-known problems inherent in comparisons of reaction times resulting from data obtained inn different speed/accuracy trade-off conditions, the reaction time data from the first replication for the Wernicke's aphasics (that with higher error rates) were dropped from the subsequent analyses.

Reaction time data for all conditions and groups were then examined, as qualified by the above stated condition. Mean reaction times for lexical decisions to experimental (related) and control items paired with each meaning of the ambiguity (primary or secondary) under each of the two sentential context bias condition (bias toward the primary or secondary meaning of the ambiguity) were calculated for each subject. These mean reaction time data are given for neurologically intact control subjects, Wernicke's aphasics, and agrammatic Broca's aphasics in Tables 2a, 3a, and 4a, respectively. In each table (Tables 2b, 3b, 4b) the same data is provided in terms of an 'amount of priming' score (reaction times to each control word minus that for its relevant `related' experimental word).[2] It should be noted that in all instances each individual within each group showed the priming effect for their group; while there were variations in absolute amount of priming, there was no change in the direction of the effects for any individual. (See Table 5 for priming scores for each agrammatic subject.)

The reaction time data from each subject population was submitted to an independent analysis of variance, with sentential bias (primary or secondary), relationship of the visually presented word to the ambiguity (primary or

Table 2

NEUROLOGICALLY INTACT CONTROL SUBJECTS

A. MEAN REACTION TIMES IN MSECS

	VISUAL PROBE WORDS			
	Primary Interpretation		Secondary Interpretation	
	related	control	related	control
SENTENCE CONTEXTUAL BIAS:				
primary interpretation	732	902	905	1017
secondary interpretation	791	863	841	1073

B, MEAN PRIMING SCORES IN MSECS (rt. to control minus rt, to related words)

	VISUAL PROBE WORDS	
	Primary Interpretation	Secondary Interpretation
SENTENCE CONTEXTUAL BIAS:		
primary interpretation	170	112
secondary interpretation	72	232

secondary meaning), experimental (related) vs. control visual word conditions, and replication (first or second), as main effects, (The Replication factor was not included for the Wernicke's aphasics analysis, for reasons given above.) As there were no significant main effects or interactions involving the replication factor for either the control subjects or the agrammatic Broca's aphasics, this factor was dropped from further analysis reported below (the mean reaction times presented in tables 2, 3, and 4 reflect this fact). In addition, prior to analysis, the data were combed for outlier points, such that any individual reaction time that was more than two standard deviations from the group mean for that data point was dropped from the analysis. This resulted in dropping five individual reaction times from the analysis of Wernicke's aphasics data and four individual dlata points from the Broca's aphasics data. These data points, representing only slightly more than 1% of the entire data analyzed, were replaced with the reaction times for the group means in the analyses.[3] The remaining reaction time data were normalized via arc-sine transformation prior to further analyses. In addition to the analysis of variance, planned paired comparisons of reaction times to experimental and control words for each experimental condition were made. These planned comparisons provide the only appropriate and critical tests of the hypotheses under consideration.[4]

As can be seen by inspection of Table 2, the age-matched neurologically intact control subjects demonstrated significant priming in all conditions, thus replicating findings for college-aged subjects already in the literature (e.g., Swinney 1979). The planned comparisons contrasting experimental (related) with control materials demonstrated that there was significant priming for visual related words in the conditions where context was biased toward the primary interpretation of, the ambiguity for both the primary ($F(1,3) = 14.6$, $p<.05$) and secondary ($F(1,3) = 12.6$, $p<.05$) meanings of the ambiguity. This significant priming effect also held when context was biased toward the secondary interpretation of the ambiguity for visual words related both too the primary ($F(1,3) = 19.01$, $p<.05$) and secondary ($F(1,3)= 17.6$, $p<.05$) meanings of the ambiguity.

Table 3 presents the mean, reaction time data for lexical decisions for the Wernicke's aphasic population. With respect to the relevant theoretical issues, these data can be seen to demonstrate the same pattern of results as that found for the neurologically intact control subjects and for previous examinations of younger subjects. The planned comparisons demonstrate that, in conditions where the contextual information was biased toward the primary interpretation of the ambiguity, significant priming was found for both words related to the primary ($t(3) = 2.43$, $p<.05$) and secondary ($t(3) = 3.12$, $p<.05$) interpretations of the ambiguity.. When the contextual information was biased toward the secondary interpretation of the ambiguity, again there was significant priming for words related to both the primary ($t(3) = 4.87$, $p<.01$) and secondary ($t(3) = 4.99$, $p<.01$) interpretations of the ambiguity.

The reaction time data for the agrammatic aphasics demonstrate a different pattern of results from those for the Wernicke's or control subjects. As can be seen in Table 4, there is significant priming for lexical decisions to words related to the primary interpretation of the ambiguity, both

Table 3

WERNICKE'S APHASICS

A. MEAN REACTION TIMES IN MSECS

	VISUAL PROBE WORDS			
	Primary Interpretation		Secondary Interpretation	
	related	control	related	control
SENTENCE CONTEXTUAL BIAS:				
primary interpretation	1833	1955	1822	1970
secondary interpretation	1378	1533	1798	1933

B. MEAN PRIMING SCORES IN MSECS (rt. to control minus rt. to related words)

	VISUAL PROBE WORDS	
	Primary Interpretation	Secondary Interpretation
SENTENCE CONTEXTUAL BIAS:		
primary interpretation	122	148
secondary interpretation	155	135

for conditions where the sentential context was biased toward that (primary) interpretation ($F(1,3) = 19.6$, $p<.05$) of the ambiguity and when it was biased toward the secondary interpretation of the ambiguity ($F(1,3) = 31.5$, $p<.02$). However, there was no significant priming for the visual word related to the secondary interpretation of the ambiguity under either contextual bias condition-either when the context was biased toward the primary meaning of the ambiguity ($F(1,3) = 1.6$, $p =.8$) or when it was biased toward the secondary meaning of the ambiguity ($F(1,2) = 0.3$, $p = .9$). Thus, it can be seen that, independent of contextual information, there appears to be significant priming only for words related to the primary interpretation of the ambiguity for agrammatic aphasics-suggesting that this is the only interpretation that they *initially* access and activate.

In an attempt to shed some light on this abnormal pattern of lexical access, some additional data were collected for the agrammatic aphasics. A baseline reaction-time condition was run on this subject population, in

Table 4

BROCA'S APHASICS

A. MEAN REACTION TIMES IN MSECS

	VISUAL PROBE WORD			
	Primary Interpretation		Secondary Interpretation	
	related	control	related	control
SENTENCE CONTEXTUAL BIAS:				
primary interpretation	1222	1329	1348	1333
secondary interpretation	1449	1576	1556	1558

B. MEAN PRIMING SCORES IN MSECS (rt. to control minus rt. to related words)

	VISUAL PROBE WORDS	
	Primary Interpretation	Secondary Interpretation
SENTENCE CONTEXTUAL BIAS:		
primary interpretation	107	-15
secondary interpretation	127	2

Table 5

BROCA'S APHASICS

Mean Priming Scores for Individual Broca's Aphasics (msecs)

	Bias Condition:	Visual Probe Words: Primary	Visual Probe Words: Secondary
Subject 1	Primary	164	6
	Secondary	111	1
Subject 2	Primary	65	-18
	Secondary	70	7
Subject 3	Primary	82	-12
	Secondary	150	-4
Subject 4	Primary	115	-16
	Secondary	135	5

which subjects listened to the same sentences which they heard during the experiment, and merely had the task of pressing a button (the same buttons used in the experiment) as soon as they saw anything at all appear on the screen in front of them. What actually appeared were the word stimuli used during the experiment, except that they were presented upside down. Although this condition does not completely eliminate a decision component, it does reduce it. That is, subjects did not have to read the material, they only had to detect the appearance of something on the screen and press the button. Mean reaction time on this task was 701 milliseconds across all subjects and trials. It is worth noting that mean reaction time for "normal" college-aged subjects on this task is in the 200 millisecond range. Thus, it can be surmised that a considerable portion of the somewhat long absolute reaction times found for the agrammatics is attributable to motor response difficulties and not to any decision process.[5]

Discussion

The three findings in this study are: 1) that neurologically intact subjects, matched in age to the aphasic patients, show priming for all senses of an ambiguous word when processing a sentence in which it occurs, regardless of the contextual bias of that sentence; 2) that fluent Wernicke's aphasic patients also show this priming pattern; and 3) that agrammatic patients show priming only for the most frequent sense of the ambiguous word-regardless of context.

The normal data uphold earlier indications that lexical access momentarily involves the exhaustive retrieval of all interpretations of a lexical item and that such retrieval is not overridden by contextual information. More generally, the present normal data sustain the notion of a language comprehension system organized in terms of encapsulated (autonomous) processes, and they sustain its corollary: that contextual constraint is not introduced wherever potentially useful, but only at select interfaces between independent processing subsystems-that is, in a fashion that provides a means of selecting among competing representations provided by an independent processing device. This organizational feature has an appealing consequence: by temporarily activating all senses of a word, a data base is provided which allows for the momentary (but, of course, unconscious) consideration of use of the less frequent, non-preferred (secondary) meaning of the word (Garrett 1982; Swinney 1982).

We need to consider the implications of our findings for accounts of comprehension limitations in the various aphasias. The data clearly suggest that the comprehension limitation for Wernicke's patients arises at a different stage in the sentence processing operation than does that of agrammatic Broca's patients. For the Wernicke's aphasics, we find no compelling evidence of a disruption at that stage at which form-based word retrieval processes are active - i.e. at the point at which the exhaustively elaborated lexical data base for the sentence comprehension device is being constructed. Rather, their limitation is to be located elsewhere, somehow involving either the formation of semantically interpretable structures based on data provided by the lexical access process or the capacity to draw semantic inferences from such structures (see also Blumstein et al. 1982; Milberg and Blumstein 1981; Rosenberg et al. 1985).

The agrammatic patients, by contrast, do show a disruption at the stage of exhaustive access of word meanings. This cannot be construed as an undifferentiated failure of "automatic processing": although the "normal pattern" of meaning activation was not found, a priming pattern that demonstrated automatic activation of the most frequent meaning of the word was clearly present.[6] Nor is it the case that the agrammatics' failure to access all lexical meanings can be attributed to a slowing of processing time such that by responding later in the sentence than do the neurologically intact subjects they can take greater advantage of context (or, alternatively, that they respond so slowly that the post-access context effects hold sway). If context were entering into this process, one would expect an entirely different pattern of results from that we obtained; the agrammatic subjects do not show facilitation for the contextually relevant meaning, independent of meaning dominance; instead, they demonstrate facilitation for the primary meaning of an ambiguous word, independent of context. As a simple piece of additional information to consider on this issue, recall that we assessed baseline reaction times for a simple visual detection task with these subjects, using the same experimental apparatus, exposures and visual stimuli (upside down and reversed) as used in the experiment. The increased reaction times observed for the agrammatic patients on this simple detection task (relative to those for the control subjects) accounts almost entirely for their increased reaction times on the lexical decision task (again, relative to the control subjects).

Overall, then, the data suggest that deficits inherent in the contrasting syndromes of agrammatic B,roca's and Wernicke's aphasia serve to bracket the operation of a lexical access device, patients from within the former category showing a disruption to this device not shown by patients from within the latter category.

The data also suggest a way of thinking about how focal brain damage can disrupt language processing. Specifically, the data suggest that lexical access in agrammatism still depends upon an encapsulated device, and correspondingly, that the problem is to be viewed as one that is *internal to the module itself* One possibility in this respect is that the module can no longer sustain parallel access. But this assumes that the normal access of ambiguous word meanings is correctly characterized as the consequence of a parallel engagement of representations. There is no compelling evidence for such an assumption, Further, if this were the case, secondary meanings of polysemous words would *never* be activated by agrammatic aphasics, and one would expect more serious comprehension impairments than one generally sees in these patients. Indeed, in this scenario, they should not have been able to paraphrase half of the sentences - those involving secondary meanings. But, they could. And, so, we are forced to consider an alternate set of possibilities: 1. that exhaustive access takes the form of a search through the range of meaning candidates within the set defined by form-driven access; 2. that the order of this search is controlled by frequency of meaning occurrence (e.g., Forster 1979); and 3. that when the number of candidates in the set is very limited, the search is normally carried out at a rate too fast for us to measure with our existing techniques. On this view, the lexical search module in agrammatism operates on a slower-than-normal rise time, only the most frequent meaning representation being engaged within the time frame imposed by the experimental paradigm, Pursuing this notion, the facilitation for all senses of an ambiguous word should eventually be shown, but at a point in the sentence that is noticeably later than that which is shown normally. We are currently investigating this.

At any rate, the agrammatic patients' failure to exhaustively engage meaning representations might be indicative of an even wider based disruption of information access-of a disruption that extends even beyond language. Thus, while the limitation observed here clearly impacts upon language comprehension, it is much less clear that the processing disruption itself is to be viewed as a diagnostic of a language-specific problem. It might well be the case that the agrammatics' inability to access lexical items in the normally exhaustive manner is but one reflection, albeit the most sensitive, of a failure to show exhaustive computation in any domain. Relevant here are preliminary data that suggest that exhaustive access is also normally a feature of processing in the nonverbal, visual domain-that neurologically intact subjects automatically (and momentarily) elaborate all interpretations of an ambiguous visual form (e.g., a necker cube) even though they only become aware of a single interpretation (organization) at any one time. Whether such elaboration is shown also by agrammatic patients is an issue that we are currently addressing, for only by examining this phenomenon in language and other realms will we be able to distinguish domain-specific from domain-general problems in aphasia.

We note also the various advantages the approach represented here has over those most often referred to as "information processing" analyses of language disorders. Both share the usual assumptions: that the language faculty can be decomposed into a set of processing components or modules, some of which are disrupted by brain damage; that the spared components do not, themselves, perform differently when one or more of the other components are not functioning normally; and that the pathological performance will provide a basis for discerning which components or modules are disrupted (Caramazza 1984). The difference between the two approaches turns on the manner by which each isolates the modules of the system, Information processing approaches typically produce modules in line with relatively uncontroversial distinctions among information types specified in linguistic theory. So, generally, there are phonological, syntactic, lexical, and semantic components--each, often, with its own buffer. To these constituents, additional components and access routes are provided as needed, whether to explain modality differences in performance (auditory vs. visual input systems) or whether to account for "linguistically related" symptoms such as the relative sparing of concrete as opposed to abstract nouns or of open class items as opposed to closed class items (e.g. Coltheart, Patterson, and Marshall 1980, and chapters therein).

By contrast, the approach taken here does not stipulate a module as a direct consequence of partitions in linguistic theory, nor does it provide a module (together with its functional lesion) solely as a means of redescribing the patterns of sparing and loss in aphasia. Rather, evidence for a module in the present analysis emerges as the consequence of charting a mandatory real-time operating characteristic of the comprehension system. Thus, to the extent that our analysis has captured an informationally encapsulated operating device in the service of lexical access (a device that isn't penetrated by surrounding information and expectations), we have provided evidence for the modularity of this device. And, to the extent that we have shown that the agrammatic deficit is statable in terms of a disruption internal to this device and not to its absence-the module is not destroyed, it just works abnormally-we have provided a more suitable framework for evaluating variability and imprecision in aphasic performance. By contrast, functionally excising one or another box in an information flow diagram disallows any explanation for the often encountered pattern of suboptimal performance that is, nonetheless, above chance.

The general point here is that by not confusing modules with the linguistic objects they are intended to implement, by instead, measuring and ensuring the degree of encapsulation of any particular device in terms of on-line operating characteristics, we lessen the distance between cognitive psychology and neuroscience-the distance, that is, between descriptions of the functional architecture of language and description of its (presumably hardwired) neurological resources. In this respect, to the extent that agrammatic patients cohere as a group in terms of an underlying disruption to fast-acting processing devices (see also Blumstein et al. 1982; Milberg and Blumstein 1981), it is quite possible that this coherence is brought about by the dependence of such devices on elementary motor systems - in the sense that the motor systems serve as a resource for the automatic processing devices. If this turns out to be the case, we will have returned, in part, to Wernicke's formulations in which linguistic processes in the brain were seen as an extension of sensory-motor operations that had obvious cerebral localizing value. However, our account cannot be construed as simply old wine in new bottles. For while the component processors that we have analyzed here are possibly rooted to sensory-motor activities with discrete cortical localizations as originally formulated by Wernicke, the fact remains that such processors must, in the first instance, be identified in terms of the information they access. More than that, they must be shown to be dedicated to one or another type of information in virtue of their encapsulation during processing. Therefore we have positioned ourselves to evaluate processing devices in two ways: in terms of their cortically localizable sensory-motor resources and in terms of their computational operations and goals.

Methods

Subjects

The aphasic patients were eight males, ranging in age from 37-73 years. They were diagnosed as Broca's or Wernicke's aphasics on the basis of the Boston Diagnostic Aphasia Exam and clinical consensus. All were right handed, except as noted below.

All four of the Broca's aphasics showed an "overarching" agrammatism: their output was telegraphic and suggested also a reduction in syntactic options, and their comprehension was marked by a corresponding inability to interpret other than simple active structures or semantically constrained sentences. This comprehension pattern was discerned both on clinical workup wherein patients were asked to act out the content of active and passive sentences and on two prior experiments, one requiring sentence enactment, and the other, the solution of anagrams composed of sentence fragments expressing in their correct order a depicted relation among two people or entities.

A point must be entered here concerning the fact that we have restricted our selection of Broca's aphasics to those who show a comprehension as well as production deficit. In selecting such patients we are obviously not accounting for all patients labelled as Broca's aphasics. And, indeed, we seek to avoid "syndrome" issues of the sort that turn on whether or not all agrammatic speakers are also agrammatic comprehenders. Rather, we are concerned with selecting a group of relevance to the processing issues at stake here and this group, based on past evidence (e.g., Rosenberg et al., 1985), is one that shows the "overarching" agrammatism.

At any rate, as determined by CT Scan, three of the four Broca's aphasics had CVAs involving broadly that area of the brain implicated in Mohr's; (1976) discussion of Broca's aphasia. The first Broca's aphasic presented with a left middle cerebral artery distribution infarct involving the left posterior frontal lobe with minimal extension into the left parietal lobe. The second, who was left-handed, had a lesion involving Broca's area, motor and sensory strips, extending deep to the supramarginal and angular gyri and the lateral half of the putamen. The third, also left-handed, presented with a large infarct involving the left frontal lobe, motor and sensory strips and extending deep to the body of the lateral ventricle. The fourth and youngest patient became aphasic as a result of a gunshot wound, the bullet having entered slightly posterior to Broca's area and exiting ventrally, nicking the right frontal lobe.

The four Wernicke's aphasics, by contrast, all showed

Materials sample:

"The gardener was responsible for watering every plant* on the enormous estate."

	VISUAL PROBE WORDS	
	related	**control**
primary interpretation	TREE	PAGE
secondary interpretation	FACTORY	FUNERAL

Figure 1: Condition: contextual bias toward primary interpretation of ambiguity (The sentence in quotation marks was presented auditorily. The (*) indicates the point at which one of the visual words was presented).

fluent speech with paraphasias and some neologisms, and all had impaired comprehension. CT Scans showed that three had left CVAs with resultant left posterior damage involving Wernicke's area and the parietal lobe. One also sustained damage to the occipital lobe, although there was no evidence of accompanying alexia or deep dyslexia. One had a hemorrhage which damaged Wernicke's area and a small portion of supramarginal gyros.[7]

The neurologically intact control group consisted of four normal subjects randomly selected from a subject pool, approximately matched to the aphasic patients for age, sex, and education.

Materials and Apparatus

Twenty-four non-systematic lexical homographs were selected for the main study on the basis of pretesting. In this pretest, 44 neurologically intact subjects were presented auditorily with 120 lexical ambiguities (homographs). They were required to list the first meaning they thought of upon hearing each one. Information concerning additional meanings they thought of was also collected. From these ratings, 24 ambiguous words were chosen which met two criteria: first, they constituted words for which the most frequent ("primary") interpretation of the ambiguity-that given as the "first" meaning these subjects thought-was given at least 70% of the time; second, they were words for which the population of aphasic patients knew both meanings. These 24 "polarized" lexical ambiguities thus constituted the core of the materials for the experiments to be detailed below.

For each of the 24 ambiguities, a set of four words, to be used as visual probes for the examination of priming, was created. This set comprised one "experimental" word which was semantically related to the primary meaning of the ambiguity, one "experimental" word which was semantically related to the secondary meaning of the ambiguity, and two control words which were semantically unrelated to the ambiguity, but which were matched to the "related" words in frequency and length (each control was matched to one experimental "related" word). These 24 sets of four words were submitted to a pretest involving 29 neurologically intact subjects. Subjects were required to make lexical (word/nonword) decisions to each of these items which were presented along with an equal number of non-word stimuli (non-words were all orthographically legal) in order to determine whether there were any a priori reaction time differences between each word and its matched control. Analysis of reaction time data to these word stimuli revealed a 7 millisecond advantage (faster) for control words as compared to experimental ("unrelated") words. This did not constitute a statistically significant difference, and thus it was judged that no a priori differences existed between experimental and control words (as expected due to the matching procedure used to create these words).

Each of the 24 lexical ambiguities was placed into a sentential context. Twelve of these were placed into sentential contexts that were judged to be biased toward the primary interpretation of the ambiguity, and the other 12 were placed into contexts which were biased toward the secondary interpretation of the ambiguity. In all cases, the portion of the sentence which created the bias toward one or another of the interpretations of the ambiguity preceded the ambiguity in the sentence. Thus, these constituted "prior" contextual biases. These 24 sentences were then recorded onto auditory tape along with 19 other randomly interspersed sentences (these latter 19 sentences were filler sentences, chosen to be of approximately the same length and structure as the 24 experimental sentences), and preceded by 5 practice sentences. Thus, a total of 48 sentences were recorded.

From the visual letter-string materials (see above), four "presentation lists" were created: each list contained 19 orthographically legal non-word stimuli (these non-word stimuli were paired with the filler sentences in the experiment) and 24 words, consisting of one of the four test words for each of the experimental sentences (those containing ambiguities). The words were assigned to a "presentation list" in a manner such that only one word of the four in the set linked with each ambiguity occurred in any one list, and so that words related to either the most likely or least likely interpretations and their controls appeared with equal frequency in each list. In addition, for each presentation list, the initial 5 items were created to be presented with the initial 5 practice sentences. These practice materials consisted of three non-word and two word stimuli. The non-word and practice stimuli were identical for all four "presentation lists". Figure 1 presents a schematized example of the materials for one ambiguity.

In sum, the experimental materials consisted of one tape recording containing 5 practice items, 24 experimental items, and 19 "filler" items. Half of the experimental items were biased toward the primary interpretation of the ambiguity and half were biased toward the secondary meaning. This tape recording was paired with four different "presentation lists", which were counterbalanced for the four critical test conditions.

A Sony TC 66 reel-to-reel tape recorder was used to record the auditory materials and to present them to subjects (over circumaural headphones). The recording was made by a male speaker (who was practiced at speaking for auditory recording) in a "neutrally" intoned presentation, speaking at a normal rate. Presentation of visual letter strings was controlled and coordinated with auditory (tape) presentation by placing a tone (which was not heard by the subjects) on the auditory tape exactly coincident with the offset of the homograph in each experimental sentence (or at a similar position in the sentence for filler condition). This tone was "registered" through a Uher diapilot which instantly opened a projection t-scope shutter and initiated timing in a Lafayette millisecond clock-counter. A buttonpress device (used by the subjects) terminated the timing of the clock-counter. Visual words were presented through the projection t-scope, on a rear-projection screen. The words, when presented, were centered foveally.

Procedure

Subjects were tested individually in sessions of approximately one-half hour duration. Each subject was seated at a small table in front of a rear-projection screen. On the table was a reaction time device consisting of two telegraph keys placed approximately 5 inches apart. Since the agrammatic Broca's patients all showed hemiparesis of their preferred hand, all subjects were asked to place their non-preferred, usually left, hand between these keys and to practice pressing the keys as rapidly as possible. The subject's hand remained between the keys throughout the experiment. The subject was then instructed that he would hear a series of sentences over the headphones, and his job was to listen carefully to each sentence and to try to understand it. Subjects were told that they would be required to indicate their comprehension of the sentences several times throughout the course of the experiment by being asked to paraphrase what they had just heard. This was done two times during the experiment. The subject was also told that there would be a second, simultaneous, task they would have to perform: they would see a string of letters appear on the screen in front of them at some point while hearing each sentence, and they would have to decide, as quickly and accurately as possible, whether the string of letters formed a word or not (where "word" was defined to them as being anything they recognized for certain as a word they knew). Subjects were then given practice on the five practice trials, which were repeated as often as necessary until the experimenter was satisfied that the subject was performing the two tasks appropriately and with ease. We note here that of the two most common methods used to assess semantic priming -lexical decision and naming -we used only the latter because of the verbal output problems found in Broca's aphasia.

Each subject was tested two times. In the case of the agrammatic Broca's aphasia patients and the age-matched neurologically intact control subjects, each subject was tested on the same "presentation list" two separate times. The Wernicke's aphasics were tested on two different "presentation list" conditions. One subject had the two tests administered on two successive days. In all other cases, the second administration of the "presentation list" was separated from the first by at least one month.

Notes

1. There is a small literature on a putative phenomenon known as "backward priming" (Kiger & Glass, 1983) which has been claimed by Glucksberg, Kreuz and Rho (1986) to put the interpretation given for these results in jeopardy. This deserves some brief comment here, although several more recent pieces of work demonstrate that the claims for "backward priming" are not supportable as presented (see, e.g., Prather and Swinney 1988; Burgess, Tanenhaus & Seidenberg 1988). In short, the claim is that the effect obtained by (for example) Onifer and Swinney (1981) is caused by the following: appearance of the lexical decision target item related to the contextually-irrelevant interpretation of the ambiguity causes re-analysis of the ambiguity which has just been heard in the sentence (and for which only the contextually-relevant interpretation was originally accessed, in this view) such that "other" meaning of the ambiguity then gets activated, which then, in turn, helps the ongoing lexical decision (which started this effect) for that target. This claim hinges on results reported by Kiger and Glass, 1983, who obtained an effect in the visual domain (only) of a lexical decision to a word presented initially for 50 msecs by a semantically related word that followed such presentation 30 msecs later. It is critically important to note that this effect was obtained only with these timing constraints (others were tried), only for visual-visual presentation (where modality interference effects are notorious) AND that the effects obtained are far better described as a lessening-of-inhibition effect rather than any sort of priming effect. Importantly, many attempts to replicate this effect cross-modally have failed to find ANY evidence of such an effect, and the effect itself in the visual domain has also been remarkably resistant to replication (See, e.g,. Prather and Swinney 1988; Forster, personal communication). Now, Glucksberg et al performed an experiment ASSUMING that there was such a thing as backward priming. They did not, in any sense provide a test of backward priming. Their results with non-words are most easily interpretable as effects driven by prior material in the sentence which have nothing to do with the presence of any ambiguity. Further, a careful analysis of the post-hoc control conditions run by Glucksberg et al reveals that their effect actually obtains in only one of their experimental conditions. Finally, Burgess, Tanenhaus, & Seidenberg (1988) have demonstrated that the Glucksberg results were a function of the particular conditions they chose. There is simply not sufficient space to give adequate argument about all of these, and other related, issues here. However, it is the case that the interpretation of the results provided above (in the text of this paper) are secure, and are not susceptible to interpretation by a "backward priming" argument given everything that is known in this field.

2. It is important to note that the issues addressed in this paper all concern existence proofs-that is, proof of whether there is or is not any priming for lexical decisions for words related to each of the meanings of the ambiguity. For a large number of reasons, the *magnitude* of the priming effect is not interpretable. While the mean differences in reaction times which constitute priming do differ in magnitude, it is inappropriate to attempt to interpret these differences with respect to the issues at hand. One of the many reasons for this stems from the fact that the degree

of relationship holding between each of the "related" words used to probe for activation of meanings of the ambiguity and the ambiguity itself were not equated (a difficult, if not impossible, task given the other materials' constraints in the design of this experiment). So, on the one hand, there exist a priori differences between the degree of this relationship for these two conditions (primary and secondary). On the other hand, however, even these differences resist interpretation. Specifically, in each instance, both of the "related" probes were high associates of the ambiguous word and there is no finding in the literature to suggest that differences within a high associative category can yield systematic differences in priming. Yet another reason concerns the fact that the contextual words which constitute the "bias" of the sentence provide an additional source of potential information which may add to the priming effect for the contextually relevant meaning. The potential nature of this effect is, despite the large literature on priming, undetermined. These and other sources of confound preclude any possible interpretation of the magnitude effects of the priming found here. Thus, the only appropriate interpretation of these data centers around the existence-proof aspect of these data - whether there is or is not priming - indicating activation of the various meanings of the ambiguity (see also, footnote 5).

3. In the interest of conservatism, the same analyses were performed replacing these data points with the cut-off values rather than the group means. As might be expected from the small number of replaced data points, this alternate analysis resulted in no changes in the analyses reported in the paper (and no individual mean reaction time was changed by more than 1 millisecond).

4. As can be seen, the complex analyses of variance cannot provide critical tests of the hypotheses, tests which require contrasts of experimental and control words for each of the contextual bias conditions in each of the probe-word (primary or secondary) conditions. At best, one can get some sense of whether these effects hold by looking at the complex interactions in the ANOVA involving these factors. However, even this is extremely misleading; as discussed above (see note 3), the absolute reaction times, and even the absolute level of the "amount of priming" (magnitude) scores are largely meaningless in this experiment. The only interpretable evidence involves "existence proofs" of whether priming was or was not present. However, in the interest of providing maximum available information, the results of the analyses of variance for independent variables for each subject population are provided here for inspection.

The analysis of variance for the age-matched neurologically intact control subjects demonstrated a significant experimental vs. control visual word effect ($F(1,7) = 11.74$, $p<.02$) and a significant effect in reaction time between visual words in the two different (primary and secondary) meaning conditions ($F(1,7) = 8.62$, $p<.03$). There were no other significant main effects or interactions in the analysis for this control group. The Wernicke's aphasic patients demonstrated no significant main effects or interactions in the analysis of variance on the data (note the reduced n compared to the other populations; see Results) except for an interaction of exemplars and experimental/control items ($F(2,6) = 7.48$, $p<.03$). Finally, the analysis of variance for the agrammatic Broca's aphasic patients revealed one significant main effect (for contextual bias; $F(1,7) = 9.55$, $p<.02$) and one significant interaction (for exemplars and contextual bias; $F(2,14) =8.13$; $p<.01$).

5. It is worth noting that subjects in these experiments made responses by having to move a single hand which was placed between two response buttons. In the experiments in the "normal" literature using the lexical decision task, subjects typically keep one hand resting on one response button (e.g., the non-word button) and the other hand resting on the other response button. Thus in the present experiment, some elevated reaction times are to be expected due to the absolute time it takes for an initiated hand movement to actually be completed through this greater than "normal" distance.

6. Milberg and Blumstein (1981) and Blumstein, Milberg, & Shrier (1982) report that Broca's do not show priming with highly associated word pairs. Yet, while their Broca's did not show a statistically significant effect, there was some tendency to prime. Importantly, however, these studies employed an isolated word processing paradigm, while we have (assessed priming in the context of sentence processing. And this methodological difference must be carefully investigated as, indeed, must all methodological differences. So, for example, while Milberg, Blumstein, & Dworetsky (1987) observed no significant priming for Broca's in the processing of lexical ambiguity using a triplet paradigm, Katz (1986), using the same stimulus items but recasting them as pairs, did observe priming for this group. In any event, we cannot, at present, gauge the relevance of priming patterns in word list tasks for understanding word access during the course of sentence processing.

7. The Wernicke's patients were also tested on the sentence enactment task referred to above in connection with the agrammatic patients. They showed roughly the same pattern as the latter, that is, better performance on active than on passive sentences. We have, nonetheless, examined these Wernicke's patients to test the notion that the similar comprehension limitations sometimes shown by agrammatic and Wernicke's patients have different processing antecedents and, more pointedly, to test the notion that these different processing problems bracket the level of processing at issue here. In a broader context, it is worth noting that our use of group data reflects our feeling that, contrary to recent claims (Badecker and Caramazza 1985), neuropsychological inquiry ought not to be set apart from other forms of cognitive science and, in particular, that attempts at theory construction ought not to proceed only via "exhaustive individual patient analysis" given the absence of any criteria as to what constitutes exhaustivity of such analysis. We think, rather, that theoretical generalizations can be well served by group comparisons as long as the groups are chosen to be of relevance to a particular theoretical issue. So, in the present instance, and as already noted for the agrammatic patients, our choice of particular types of Broca's aphasic patients and Wernicke's patients has been motivated by our hypothesis that certain properties of lexical access are "neurologically" dissociable from other aspects of sentence processing and by the relevance of these two particular (sub)groups to the hypothesis (see also Rosenberg, et al.. in press).

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