Functional Localization in the Brain with Respect to Syntactic Processing

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This report describes some recent examinations of the ability of aphasic patients to construct syntactically governed dependency relations in real time. The data show that Wernicke's patients can link the elements of dependency relations in the same way as neurologically intact subjects, even for sentences that they do not understand. Broca's patients, by contrast, are shown to be unable to create such links, even for sentences that they do understand. These data underline the isolability of this stage of syntactic analysis and they suggest that comprehension limitations statable in syntactic terms can be traced to changes in cortically localizable processing resources.

Much of aphasia research is concerned only with evaluating cognitive theory. The goal is to determine whether distinctions within a linguistic or psycholinguistic theory are neurologically defensible, that is, whether these distinctions correspond to patterns of sparing and loss following brain damage. No closer relation is sought with neurology (Caramazza, 1992). This is not so for the work reported here, however. Our results not only bear upon theories of sentence processing, but also make claims about functional neuroanatomy. In this paper we will connect a syntactic failure to a neurolog-

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ically localizable processing disruption, and, in doing so, we will provide a basis for inferring how different brain regions normally serve aspects of syntactic analysis.

The connection to functional neuroanatomy turns on the fact that the syndromes we examine here-Broca's aphasia and Wernicke's aphasia-are distinguishable both clinically and with respect to lesion site. To be sure, the brain area associated with Broca's aphasia now seems to have greater extent than initially proposed: Broca's area in the foot of the third frontal convolution is no longer considered to be singularly important; adjacent and deeper areas have also been implicated (Alexander, Naeser, & Palumbo, 1990; Naeser, Palumbo, Helm-Estabrooks, Stiassny-Eder, & Albert, 1989). Still, the fact remains that the modal lesion site for Broca's area is distinguishable from that for Wernicke's aphasia, for which, in line with early descriptions, the greatest involvement is still considered to be in the superior temporal gyrus (Wernicke's area). Our work will be seen to capitalize on this difference-on the fact, that is, that each of these two aphasias has localizing value.

SENTENCE COMPREHENSION IN APHASIA: REPRESENTATIONAL CONSIDERATIONS

Both Broca's aphasic patients and Wernicke's aphasic patients show comprehension problems at the sentence level. But analyses along syntactic lines have been put forth only for Broca's patients, not for Wernicke's: The comprehension problem seems more structurally focussed-more nearly restricted to syntax-for Broca's than for Wernicke's. To state the matter simply, comprehension for Broca's patients is particularly vulnerable for sentences which can be characterized as containing traces in object positions (e.g., Ansell & Flowers, 1982; Caplan & Futter, 1986; Caramazza & Zurif, 1976; Goodglass, 1968; Grodzinsky, 1986, 1989; Hickok, Zurif, Canseco-Gonzalez, 1993; Wulfeck, 1988).[4]

[4] There are exceptions to this generalization. At least one reported patient has a comprehension pattern that appears to resist any kind of structural interpretation (Badecker, Nathan, & Caramazza, 1991). And there are several case reports of patients with production impairments but no discernible sentence comprehension impairment (e.g., Kolk, Van Grunsven, & Keyser, 1985; Miceli, Mazzucchi, Menn, & Goodglass, 1983; Nespoulous et al., 1988). As a general point, however, the many Broca's patients who do show interpretable sentence-level comprehension problems considerable outweigh those that have no such problem. In effect, the importance of these exceptions is blunted; they fail to fit the overall structure of accumulated evidence. Moreover, some of these exceptions do not even appear to be Broca's to begin with: Case 1 of Miceli et al. (1983) was able to repeat and read aloud without any agrammatic limitation and Case 2 showed normal fluency and normal phrase length, as did Kolk et al.'s (1985) patient.

To account for this selectivity, Grodzinsky (1986, 1990) and others (Hickok, 1992; Mauner, Fromkin, & Cornell, 1993) have argued that the Broca's patients cannot represent traces and cannot, therefore, grammatically assign thematic roles to moved constituents. Faces with thematically unassigned phrases, the patients rely on nongrammatical strategies-for example, on the strategy of assigning the thematic role of agent to the first encountered noun phrase in a sentence (Bever, 1970). When a constituent is moved from subject position, the strategy works-were grammatical capacity normal, it would yield the same solution. When the movement is from object position, however, the strategy yields two agent noun phrases for the same sentence. One is assigned by the normal grammatically based procedure in which assignment is given in terms of the sentence's overall hierarchical configuration; the other, as mentioned, is incorrectly assigned by a nongrammatical strategy sensitive only to linear order. Faced with two agents, the Broca's patient is forced into guessing and performs randomly on such tasks as picture matching or enactment. For example, in the sentence *It was the dog$_i$ that the boy chased (t)$_i$*, the Broca's patient is hypothesized to assign agency to both *the dog* and *the boy,* the latter assignment being grammatically based, the former being due to the misapplication of the agent-first strategy-a default strategy employed in the face of an inability to represent the link between the moved constituent *the dog* and the trace in the site from which it was moved.

SENTENCE COMPREHENSION IN APHASIA: PROCESSING CONSIDERATIONS

The foregoing serves as a descriptive generalization only. It describes what can and cannot be syntactically represented for comprehension purposes by Broca's patients. What we now address is the possible source of this representational limitation.

A first question in this respect is, whether the limitation reflects some loss of syntactic competence or rather a disruption to the processes that implement'syntactic knowledge in real time. And the answer appears to be the latter.

Comprehension Versus Grammatical Judgment

This notion arises from the observation of a dissociation between comprehension and grammatical judgment performance. Specifically, Linebarger, Schwartz, and Saffran (1983) have reported that Broca's aphasic patients who showed the standard syntactic limitation in comprehension were, none-

the less, able to detect a wide variety of grammatical deformations, including those that required an awareness of syntactic dependencies involving traces. What emerges from this is a picture of Broca's patients in which they can be seen to carry out quite complex syntactic judgments, yet lack the ability to exploit this sensitivity for comprehension. In effect, the patients seem to retain knowledge of syntactic structure, and, therefore, their inability to represent traces must be due to some defect in the comprehension system, itself-in the system that converts the input stream into an interpreted structure. So these judgment data do, indeed, suggest the need for a processing explanation of the syntactic limitation in Broca's aphasia. But of what. sort?

Lexical Access

The studies to be described here bear directly on this question. These studies have widened the focus to include Wernicke's aphasic patients as well as Broca's patients. They build upon earlier observations in the form of data from lexical priming experiments showing that Wernicke's patients, but not Broca's patients, exhibit roughly normal lexical activation characteristics in circumstances that support automatic processing (e.g., Milberg & Blumstein, 1981; Milberg, Blumstein, & Dworetsky, 1987; Prather, Zurif, & Love, 1992; Prather, Zurif, Stern, & Rosen, 1992; Swinney, Zurif, & Nicol, 1989). Priming in this case refers to the finding that processing a lexical item (for example, deciding whether or not a string of letters forms a word) is faster for target words when these are immediately preceded by semantically associated words than when preceded by unrelated words (e.g., Meyer, Sclvaneveldt, & Ruddy, 1975; Neely, 1977). In effect, activation of the first, or prime, words aids recognition of the target. So, to state the matter directly in terms of the data, Wernicke's patients, but not Broca's, show the normal pattern of faster word recognition (lexical decision) in semantically facilitating contexts.[5]

That noted, we hasten to add that the Wernicke's patients are not likely to be entirely normal in accessing word meaning. To be sure, the priming data for this group ought to be interpreted as reflecting lexical activation (the point of interest here), but these data do not rule out "coarse-coding"

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[5] Contrary to the view expressed here, Ostrin and Tyler (1993) claimed that Broca's patients can carry out normally rapid automatic lexical activation. Their claim, however, was based on their use of a word-pair paradigm without any distraction manipulation of the sort used by Neely (1977). This methodology elicits, not automatic lexical activation, but controlled or strategy-driven processing (Prather, in press; Shelton & Martin, 1992). It seems that setting words together in pairs suggests to subjects that the words somehow belong together and it fosters a post-lexical checking strategy (Shelton & Martin, 1992) of no apparent relevance to sentence processing.

and, therefore, ultimate imprecision within the semantic network. Contrari-wise, the priming data should not be taken to indicate that Broca's patients are disbarred from activating word meanings. In fact, they are not completely insensitive to prime-target relations. Rather, for these patients, automatic priming seems only to be temporally protracted: Automatic lexical activation seems still to be present, but to operate under a slower-than-normal time course (Friederici & Kilborn, 1989; Prather, Zurif, & Love, 1992; Prather, Zurif, Stern, & Rosen, 1992;-Swinney et al., 1989).

Gap-Filling

In an earlier issue of this journal devoted to sentence processing, we speculated on the connection between the Broca's patients' aberrant (slowed-down) activation patterns and their syntactic limitations (Prather, Shapiro, Zurif, & Swinney, 1991). Our discussion focused on the real-time processing consequences of traces, that is, on gap-filling, the demonstration (based on priming) that antecedents and traces are linked during the course of com-prehension. [See Swinney and Fodor (1989) and Swinney and Osterhout (1990) for reviews of this work.] This is an operation that is implemented under strict time constraints. And in light of the Broca's slower-than-normal lexical activation capacity, we suggested that their syntactic limitations, namely, their failure to form antecedent-trace chains, could be viewed as an inability to reactivate moved constituents *at the normal time in the process-ing sequence* - in time, that is, to fill gaps left by their movement.

We have since examined this suggestion by assessing gap-filling in Broca's patients and Wernicke's patients in two experiments (Swinney, Zu-rif, Prather, & Love, 1993; Zurif, Swinney, Prather, Solomon, & Bushell, 1993).[6]

In the first experiment (Zurif et al., 1993) we used subject-relative con-structions of the sort *The man liked the tailor$_i$ with the British accent who (t)$_i$ claimed to know the queen.* As shown by this example, movement from subject position is hypothesized.[7]

We chose this construction because of the perspective it afforded both within and across aphasic groups. The relevant point in this respect is that Broca's and Wernicke's patients differ, not only in terms of lexical access characteristics, but also in their ability to understand the subject-relative construction. Broca's patients, as already indicated, show relatively normal

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[6] We have also assessed gap-filling in age-matched neurologically intact subjects. In fact, these subjects were used to pretest the different sentence types for the two experiments.

[7] Technically, it is the *Wh*-element (*who*) that has been moved from the subject position of the relative clause. But since *who* and *tailor* corefer, *who* inherits the semantics of *tailor.*

comprehension for this construction. But Wernicke's patients are unpredict-able, more often than not showing chance comprehension (Grodzinsky, 1984; Shankweiler, personal communication, February 1992). So for Broca's patients these sentences provided the strongest test of our suggestion that they could not carry out normal syntactic analysis in real time: We could determine if slower-than-normal lexical activation disallowed normal gap-filling even for sentences correctly comprehended, and we could determine if even in such circumstances Broca's were abnormally reliant on nongrammatical strategies. As for Wernicke's patients, these constructions allowed us to determine the possibility of a reverse scenario: viz., whether they could fill gaps even for sentences which such patients often fail ultimately to understand.

Our assessment of gap-filling and the range of possibilities just outlined, relied on a cross-modal lexical priming (CMLP) paradigm (Swinney, Onifer, Prather, & Hirshkowitz, 1979). Subjects listened to a sentence over earphones (delivered uninterruptedly and at a normal speaking rate) and at one point, while listening to the sentence, were required to make a lexical decision for a visually presented letter string flashed on a screen in front of them.

What we sought to discover was whether a letter-string probe forming a word related to the moved constituent (the antecedent) was primed at the gap. Such priming would indicate that the moved constituent was reactivated at the gap (thus providing the prime). So for each of our experimental sen-tences, we recorded lexical decision times either for antecedent-related probes or for letter string probes that were semantically unassociated control words. For the example given earlier, *The man liked the tailor$_i$ with the British accent*[*1] *who*[*2] *(t)$_i$ claimed to know the Queen*, the probes were *clothes* (the probe for the antecedent *tailor)* and *weight* (the control probe).

As indicated by the superscripts [*1] and [*2], priming was examined at two points-at the gap indexed by the trace (superscript [*2]) and at a pregap position (superscript [*1]). The latter served as a baseline; it allowed us to distinguish structurally governed reactivation at the gap site from any resid-ual activation due simply to the earlier appearance of the antecedent (*tailor*). Of course, in each instance, priming was determined by comparing the lex-ical decision time for the related probe to that for the unrelated probe.

The findings for the aphasic patients are presented in Table I. The data are clear: The Wernicke's patients reliably filled gaps [as did our neurol-ogically intact subjects who were used to pretest the sentences (see footnote 6)]. The Broca's patients did not fill gaps.[8] It appears, therefore, that the

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[8] We emphasize that the Broca's failure to show gap-filling cannot be construed as some global failure to prime. In other nonsentence circumstances-when presented either with word pairs or word lists-the patients did show priming, even if in a temporally pro-tracted manner.

Table I. Amount of Priming (in msec) (Reaction Time to Control Probes Minus Reaction Time to Related Probes)

	Position	
	Pregap	Gap
Wernicke's patients	44	125*
Broca's patients	-20	-68

* Significant priming (p < .03).

brain areas respectively implicated in Broca's and Wernicke's aphasia have different functional commitments-the former is crucial for the real-time construction of intrasentence dependency relations in a way that the latter is not.

As mentioned earlier, we also carried out a second study (Swinney et al., 1993). This time we used object-relative sentences. Given the Broca's failure to fill gaps for subject-relatives (sentences that they understand), we had little expectation that they would show gap-filling for object-relatives (sentences that they fail to interpret). However, our interest in using object-relatives had to do mostly with Wernicke's patients. We wanted to broaden the base of our observations of this group's gap-filling capacity, particularly because movement within subject-relatives has the special property of being "string-vacuous" (e.g., Clements, McCloskey, Mating, & Zaenen, 1983): Such movement does not reorder any of the elements of the sequence.

Accordingly, our second study featured object-relative sentences of the type *The priest enjoyed the drink$_i$ that the caterer was[*1] serving[*2] (t)$_i$ to the guests.* We used the same CMLP task as in the first experiment, and again, we checked for priming both at the gap (superscript *2) and at a baseline, pregap position (superscript *1). For the example given, *wine* was the probe for *drink,* and *boat* was the control probe.

The data for the aphasic patients in this second study are presented in Table II. As can be seen, the Broca's patients did not show significant priming at either probe site. Still, they did show some advantage for related probes (relative to control probes) at the pregap position. In effect, for this group there was no sign of structurally determined reactivation of the antecedent, only a sign of some residual activation-the consequence, likely, of having processed the earlier appearance of the constituent in a slowed-down fashion. As for the Wernicke's patients, they once more showed priming at the gap and only at the gap, and again, this pattern corresponded to that shown by the neurologically intact subjects with whom we pretested the material.

Table II. Amount of Priming (msec) (Reaction Time to Control Probes Minus Reaction Time to Related Probes)

	Position	
	Pregap	Gap
Wernicke's patients	3	108*
Broca's patients	122	-9

* Significant priming (p < .02).

CONCLUDING REMARKS

The line of research described here has only just begun. We have yet to determine, for example, whether Wernicke's patients reactivate only structurally appropriate constituents at gaps. Still, even at the present stage of our work, the data point rather convincingly to the Wernicke's patients' sensitivity to trace locations and to their ability to fill these locations as sentences unfold.

The data reported here for the Wernicke's-alongside findings reported by Shapiro and his colleagues (Shapiro, Gordon, Hack, & Killackey, 1993; Shapiro & Levine, 1990; Shapiro, Zurif, & Grimshaw, 1987, 1989)-also guide speculation concerning the processing stage at which antecedent reactivation normally occurs. Shapiro et al. have shown that Wernicke's patients are insensitive in real time to the argument-taking properties of verbs. Unlike neurologically intact subjects, the patients are unable to access momentarily all of the possible argument structure configurations within a verb's entry. They are unable, that is, to generate a fully elaborated thematic grid in the normal manner. Accordingly, it seems reasonable to view gap-filling as being syntactically, not thematically, driven-as reflecting processing at a stage prior to the full availability of a verb's argument structure and to thematic role assignment. Indeed, the fact that the Wernicke's patients filled gaps in sentences for which they show uncertain comprehension strengthens this possibility. But however gap-filling is eventually to be understood, the present data indicate that the brain region implicated in Wernicke's aphasia may not be crucially involved in the activity.

By contrast, the brain area associated with Broca's aphasia does seem to be necessary for gap-filling. Broca's patients seem to lack the processing resources to form trace-antecedent chains in real time. Presumably, therefore, they rely abnormally on nongrammatical strategies and when such strategies yield incorrect solutions, their comprehension fails.

It will be apparent that the foregoing characterization (1) connects directly to earlier descriptions of the syntactic limitations associated with Bro-

ca's aphasia (e.g., Grodzinsky, 1986) and (2) that it is based on considerations of a change in the speed of lexical activation. In this view, then, structural limitations statable in the abstract terms of linguistic theory can be traced to alterations in cortically localizable processing resources; neurological specialization for particular aspects of language can be seen to reflect the anatomical distribution of fairly elemental processing resources.

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