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An On-Line Analysis of Syntactic Processing in Broca's and Wernicke's Aphasia

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This paper is about syntactic processing in aphasia. Specifically, we present data concerning the ability of Broca's and Wernicke's aphasic patients to link moved constituents and empty elements in real time. We show that Wernicke's . aphasic patients carry out this syntactic analysis in a normal fashion, but that Broca's aphasic patients do not. We discuss these data in the context of some current grammar-based theories of comprehension limitations in aphasia and in terms of the different functional commitments of the brain regions implicated in Broca's and Wernicke's aphasia, respectively.

INTRODUCTION

Comprehension in Broca's Aphasia: Representational Considerations

Most Broca's aphasic patients show sentence-level comprehension impairments.[1] Their comprehension is particularly vulnerable when one ele-

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[1] A few Broca's patients do not show sentence-level comprehension problems (Kolk et al., 1985; Miceli et al., 1983; Nespoulous et al., 1988). But since those that do far outweigh those that do not, the exceptional cases must be considered as checks that cannot yet be cashed. They may be anomalous (outlier) subjects. Or they might disprove the notion that lesions that cause agrammatic output also cause problems in comprehension. And partly as a response to this last possibility-but partly also because models of syntactic production are far less detailed than those for comprehension (Bock, 1991)-very few, if any, researchers still focus on the notion of an overarching agrammatism-an agrammatism that implicates the same structures in speaking and listening. Yet, as we will try to show, even if the

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ment in a sentence must be interpreted with respect to another element in that sentence. So, for example, given sentences of the sort "Bill watched John bandage him," the Broca's patients perform at chance level, often taking "him" to refer to "John" (Caplan & Hildebrandt, 1988; Grodzinsky, 1990; Grodzinsky, Wexler, Chien, Marakovitz, & Solomon, 1992).

Another type of intrasentence dependency relation that Broca's patients are unable to deal with normally, arises as a result of constituent movement (e.g., Ansell & Flowers, 1982; Caplan & Futter, 1986; Caramazza & Zurif, 1976; Grodzinsky, 1986; Hickok, Zurif, & Canesco-Gonzalez, 1993; Wulfeck, 1988). The relevant hypothesis here is that movement of a phrasal constituent leaves a trace in S(urface) structures-an abstract, phonologically unrealized placeholder-in the vacated position. Traces are held to be crucial for the assignment of thematic roles in a sentence, such roles being assigned to hierarchically structured sentence positions regardless of the identity of the assignee. If a thematic position is filled with a lexical noun phrase then it receives its thematic role directly, but if a thematic position contains a trace (an empty category), then the trace is assigned the thematic role and the moved constituent that left the trace (e.g., the first noun phrase in a passive) gets its role only indirectly, by being coindexed (abstractly linked) to the trace (Chomsky, 1981).

The Broca's patients' problem with traces, or empty categories, has been foregrounded in several recent description generalizations (Grodzinsky, 1986, 1989, 1990; Hickok, 1992; Manner, Cornell, & Fromkin, 1990). The general hypothesis is that although Broca's patients appreciate hierarchical syntactic organization, they cannot represent traces and therefore cannot grammatically assign thematic roles to moved constituents for comprehension purposes. Faced with thematically unassigned noun phrases, the patients rely on nongrammatical strategies-in Grodzinsky's (e.g., 1986) formulation, the strategy is claimed to be that of assigning the thematic role of agent to the first encountered noun phrase (Bever, 1970); in Hickok's (1992) version, a fill-in strategy is hypothesized.

For some constructions the strategies work, for others, they do not. Consider, for example, Grodzinsky's (e.g., 1986, 1989) treatment of object-relative and subject-relative constructions: respectively, "The girl; whom the boy is pushing (t_i) is tall" and "The boy_i who_i $(t)_i$ pushes the girl is tall." (In each example, the vacated position, or gap, is indicated

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question concerning parallelism remains open, Broca's aphasia-and Wernicke's aphasia, too-continue to serve research. They continue to be mined for answers to other aspects of brain-language relations-including in this respect the topic we focus upon here: the neurological organization of the comprehension system alone.

by the trace (t) and the coindexation of the moved constituent (antecedent) and trace is shown by the subscript (i).) In the object-relative construction, the antecedent ("the girl") has been moved from object position - "the girl" is the theme of the action, not its agent - and so application of the agent-first strategy leads to miscomprehension. By contrast, for subject-relative constructions, the trace appears in the subject position. Thus, the agent-first strategy works-were grammatical capacity normal, it would yield the same solution.

This illustration reflects only a few of the details of Grodzinsky's (1986, 1990) trace-deletion hypothesis and none of those present in Hickok's (1992) reworking of it. What it does serve to emphasize, however, is the general point of these two accounts: namely, that for comprehension purposes Broca's aphasic patients are unable to represent intrasentence dependency relations involving traces. Indeed, in Hickok's formulations, the Broca's problem with traces is invoked even to account for their poor performance with dependencies involving overt pronouns.

Comprehension in Broca's Aphasia: Processing Considerations

The characterizations put forth by Grodzinsky and Hickok constitute efforts to describe what can and cannot be syntactically represented by Broca's aphasic patients. They are descriptive generalizations only; they do not address the *source* of the representational limitation-whether it reflects a partial loss of syntactic competence (knowledge) or whether it is due to a disruption to the processes that implement syntactic knowledge in real time.

There are data that do bear upon these alternatives, however, and they point rather convincingly to a processing explanation of the limitation. Specifically, Linebarger, Schwartz, and Saffran (1983) have reported that agrammatic Broca's aphasics who showed noticeable syntactic limitations in comprehension were, nonetheless, 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 agrammatic Broca's aphasic 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 (Sproat, 1986). So, the data gained by Linebarger et al. do, indeed, suggest the need for a processing explanation of agrammatic comprehension. But of what sort?

Linebarger et al. (1983) opt for a mapping explanation. In their words,

the problem arises ". . . not from a failure to parse sentences for their grammatical functions, but rather from a difficulty in assigning those functions the appropriate thematic roles."

Several points about this hypothesis warrant consideration. First, we do not think that the grammatical judgment data compel a mapping hypothesis or, more pointedly, indicate normal parsing. Sensitivity to some grammatical deformations need not depend upon the normal construction of a coherent syntactic representation. Specifically, it is one thing to notice the absence of an empty (trace) position in a deformed "sentence," and quite another matter to fill that position in a nondeformed sentence with the correct antecedent during the strictly time constrained initial structure-building stage. Sensitivity in the first instance will yield good performance on a grammatical judgment task, but only the latter capacity will yield a normally complete syntactic representation that can support subsequent thematic mapping (Wulfeck, 1988; Zurif & Grodzinsky, 1983). Indeed, this difference quite possibly implicates a hemispheric difference; as reported by Baynes and Gazzaniga (1987; Gazzaniga, 1989), the right hemisphere of "split-brain" patients can support grammaticality judgments, but cannot process syntactic information for the purpose of comprehension.

In addition, it should be noted that if there were to be a mapping problem, it would clearly not be an undifferentiated one-one that arises for all syntactic types. Schwartz and her colleagues acknowledge this by pointing to what they term a "thematic transparency effect"-viz., that agrammatic Broca's patient's have noticeably more difficulty in mapping moved noun phrases than in mapping noun phrases directly in thematic positions (Schwartz, Linebarger, Saffran, & Pate, 1987).

However, by failing to provide any evidence for the selective disruption of processing modules in terms of their real-time operating characteristics, Linebarger et al. have no basis for distinguishing mapping failures from prior parsing failures (Zurif & Swinney, in press). In fact, as the experimental work reported below indicates, when real-time processing properties are revealed through the application of an on-line analysis, parsing is observed *not* to be intact in Broca's aphasia.

The Present Approach: Broca's and Wernicke's Aphasia Compared

The analysis we present here is based on measures of early-stage lexical activation characteristics. It widens the focus to include Wernicke's aphasic patients as well as Broca's patients and it builds upon the consistently reported observation that Wernicke's aphasics have normal automatic lexical access functions and that Broca's do not. The data come from studies of lexical access involving priming (Blumstein, Milberg, & Shrier, 1982; Katz, 1986; Milberg & Blumstein, 1981; Milberg, Blumstein,

& Dworetsky, 1987; Prather, Shapiro, Zurif, & Swinney, 1991; Prather, Zurif, Stern, & Rosen, 1992; Swinney, Zurif, & Nicol, 1989). Lexical priming-facilitation in the processing of one word caused by the prior presentation of a related word-has been taken to indicate that contacting the related prime somehow lowers the recognition threshold for all words within its semantic or associative sphere (Meyer, Schvaneveldt, & Ruddy, 1975). So, to state the matter directly in terms of the data, Wernicke's patients but not Broca's patients show the normal pattern of facilitated word recognition (lexical decision) in semantically related contexts.

We hasten to emphasize, however, that Broca's patients are not completely insensitive to prime-target relations-they are not, after all, disbarred from activating lexical meanings. Rather, for Broca's patients, priming seems to be temporally protracted; lexical activation, as revealed by priming tasks, seems to have a slower-than-normal time course (Prather et al., in press; Swinney et al., 1989).

The effects of this form of aberrant lexical access may reasonably be supposed to ramify throughout the comprehension system. And our particular concern here is how an impoverished lexical data base might impinge upon the syntactic operation of linking antecedents and traces-upon just that operation that Broca's patients seem unable to carry out.

Central to this concern is the fact that traces have real-time processing consequences. Just as the presence of a relative pronoun immediately activates its antecedent, so too, in the relevant instances, traces are immediately linked to their antecedents when the traces (gaps) are encountered. This phenomenon, referred to as gap filling, reveals that antecedents actually fill the gap left by their movement. (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 this being so, the inability of Broca's aphasic patients to represent antecedent-trace relations can be viewed in real-time terms as the inability to reactivate the moved constituent at the normal time in the processing sequence-in time, that is, to fill the gap left by its movement (and indexed by the trace).

In the present experiment we have examined the possibility of this scenario-and the possibility that it holds not for all aphasic patients, but for Broca's patients only-by assessing gap filling in Broca's patients and Wernicke's patients.[2] We used subject-relative constructions of the sort, "The gymnast loved the professor$_i$ from the northwestern city who$_i$ (t)$_i$ complained about the bad coffee." As shown by this example, move-

[2] We also assessed gap filling in 16 neurologically intact subjects of roughly the same age as the aphasic patients. The sentences used for this assessment were the same as those for the present study; in fact, the neurologically intact subjects were used to pretest the sentences.

ment from subject position is hypothesized. Technically, it is the Wh element ("who") that has been moved from the subject position of the relative clause. But since "who" and "the professor" (the head of the relative clause) corefer, "who" inherits the semantics of "the professor." In sum, as indicated by the subscript (i), "the professor" must be indirectly linked to the trace in the subject position to receive its thematic role.

Our hypothesis that there is movement from subject position warrants some consideration. Such movement is referred to as string-vacuous movement; this is because the transformation does not reorder the elements in the string. Some investigators disagree with this analysis (Chomsky, 1986). Still, it remains relatively widely accepted with rather broad cross-linguistic empirical support (e.g., Clements, McCloskey, Maling, & Zaenen, 1983). And so for present purposes we assume that there *is* movement from subject position. But even were future research to reveal this not to be the optimal analysis, the main feature of our inquiry would still stand. Specifically, were there not to be a trace following the relative pronoun, we would be charting the formation of antecedent-relative pronoun links-we would still be assessing aphasic comprehension in terms of the ability to establish coindexation in real time. Moreover, under one currently active hypothesis, even in this circumstance the antecedent must eventually link to a trace. Namely, under the verb-phrase-internal-subject hypothesis (Burton & Grimshaw, in press; Kitagawa, 1986; Koopman & Sportiche, 1988), the relative pronoun occupies its surface position via movement from within the verb phrase. Therefore, a syntactic chain is formed in which the antecedent is still indirectly linked to a trace through the relative pronoun, but now the trace is in the verb phrase. However, having entered these possibilities to make the point that our study is not hostage to future linguistic developments, we again emphasize the current viability of our assumption of movement from subject position.

In any event, we chose the subject-relative construction because it offered the possibility of revealing whether the brain areas implicated in Broca's and Wernicke's aphasia are distinguishable in terms of their functional commitments to sentence processing. The relevant point in this respect is that Broca's and Wernicke's 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 comprehension for this construction. But Wernicke's patients are unpredictable, more often than not showing chance comprehension (Grodzinsky, 1984; Shankweiler, personal communication, February, 1992). Our questions, then, were these: Do Broca's patients show normal parsing, as Lineberger et al. (1983) would have it? Or does their aberrant lexical access pattern disallow normal gap filling,

requiring, in consequence, an abnormal reliance on one or another nongrammatical heuristic for thematic assignment? And to consider a reverse scenario, do Wernicke's aphasics show normal gap filling even though they often fail ultimately to achieve a normal level of comprehension for this sentence type?

Our assessment of gap filling and the range of possibilities just outlined employed an on-line task termed cross-modal lexical priming (CMLP) (Swinney, 1979; 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 word probe related to the moved constituent was primed at the gap-whether, in effect, the moved constituent was reactivated at the gap to serve as the prime.

METHODS

Subjects

The subjects in this experiment were eight male outpatients at either the Boston V. A. Medical Center or the Manhattan V. A. Medical Center. They all had left CVAs. Four of the eight patients were diagnosed as Broca's aphasic patients, and four as Wernicke's aphasic patients. In each case, diagnosis was based on the convergence of clinical consensus and the results of one or another standardized aphasia examination. Although the time interval between diagnosis and our experimental analysis varied considerably across patients, they had all retained the defining features of their initial diagnosis. So when tested by us, the four Broca's patients still presented with nonfluent and telegraphic verbal output and with relative sparing of auditory comprehension at the conversational level; and the four Wernicke's patients still had fluent, relatively empty speech and three of the four also had noticeable comprehension impairments.

In what follows, we list the age and educational level of each patient, the aphasia examination on which each was initially assessed, and with one exception, each patient's score on a picture matching test of active and passive voice sentence comprehension-a test that was administered around the time of our experimental inquiry. We also note when each patient suffered his stroke, and we briefly describe the available neuroradiological findings.

Broca's aphasic patients. RD is 75 years old with 2 years of college education. The Boston Diagnostic Aphasia Examination (BDAE) (Goodglass & Kaplan, 1972) administered in 1978 conformed the clinical impression of Broca's aphasia. He also exhibited the typical Broca's pattern on our test of sentence-level comprehension, performing better with semantically reversible active sentences (100%) than with semantically reversible passive sentences (60%). RD had two left CVAs-one in 1976 and the other in 1977. A CT scan administered in 1978 indicated two lesions, one in Broca's area with deep extension to left frontal horn and involving lower motor cortex (face and lip regions), the other in the left temporal lobe which spared, however, most of Wernicke's area.

FC is 59 years old with a college education. He was diagnosed as a Broca's aphasic via the BDAE administered in 1982 (and as with all other patients in this study, also on the basis of a clinical workup). On our comprehension test, he scored-in the fashion of most Broca's aphasic patients-better on actives (95%) than on passives (70%). These patterns

arose consequent to a left CVA suffered in 1973, with complete occlusion of the left central artery. There are no radiological data available for this patient.

RH is 52 years old with a high school education. The BDAE administered in 1983, in agreement with clinical findings, indicated that he was a Broca's aphasic patient. And on our comprehension test he also showed the Broca's active-passive difference, scoring 90% correct for the former and 20% for the latter. He suffered a left-sided CVA in 1983. No radiological report was available for this patient.

RR is 42 years old with a high school education. His profile on the Western Aphasia Battery (WAB) (Kertesz, 1982) administered in 1991 is consistent with the clinical diagnosis of Broca's aphasia, as are his scores on our comprehension test: 80% correct for active sentences and 40% correct for passive sentences. He suffered a left-sided CVA in 1990, and a CT scan, carried out 2 months later, revealed an ischemic infarct within the territory of supply of the left middle cerebral artery, including posterior extension into the parietal lobe.

Wernicke's aphasic patients. JC is 68 years old with a college education. His performance on the WAB administered in 1986 confirmed the clinical diagnosis of Wernicke's aphasia. Although his comprehension at the sentence level was observed to be impaired on this standardized test, we have no independent assessment available-we were unable to recall him for our active-passive sentence comprehension test. He suffered a hemorrhagic left CVA in 1986. And a recent CT scan revealed solid lesions in Wernicke's area and the left temporal isthmus.

CC is 65 years old and has a high school education. He was administered the BDAE in 1984 and in accord with clinical consensus was diagnosed as a Wernicke's patient. Still, we note that he scored highly on our sentence comprehension test: 100% on actives and 90% on passives. He suffered a left CVA in 1984 and a CT scan done approximately 1 month after the stroke revealed two lesions, one involving a portion of the posterior temporal lobe, including the posterior half of Wernicke's area, with superior extension into supramarginal and angular gyrus areas (surface and deep), and a second in the occipital lobe.

WD is 67 years old with schooling through the ninth grade. The BDAE administered in 1991 confirmed the clinical diagnosis of Wernicke's aphasia. He scored 70% correct for active constructions and 40% for passive constructions on our comprehension assessment. He suffered a left CVA in 1991 and a CT scan done a month and a half later showed a lesion in the posterior half of Wernicke's area, continuing into the supramarginal gyrus and deep to angular gyrus.

JM is 55 years old with a high school education. Clinical consensus and the BDAE carried out in 1986 converged on the diagnosis of Wernicke's aphasia. On our comprehension assessment he scored at the 100% level for active sentences and at the 80% level for passives. His left CVA occurred in 1986 and a CT scan done 2-3 weeks later revealed a vague patchy lesion involving the temporal isthmus which likely interrupted the auditory fibers from the medical geniculate nucleus before reaching Heschl's gyrus and Wernicke's area. The patchy lesion extended superiorly into the posterior supramarginal and angular gyrus areas with deep extension to the border of the left lateral ventricle, interrupting fibers of the auditory contralateral pathways.

We note, in summary, two features of these patient profiles. First, although we do not have neuroradiological findings for all patients, the data that we do have broadly confirm current views on lesion localization (Benson, 1985; Mohr, 1976; Vignolo, 1988): The two Broca's patients for whom CT scan data are available both have left-sided prerolandic lesions (although, as is common, the damage is not restricted to this region). By contrast, all four Wernicke's patients have only posterior lesions, these being located mostly within the temporal lobe and the retrorolandic region of the left hemisphere. Second, the two groups were distinguished by their performance patterns on our sentence comprehension test: whereas all four Broca's patients showed the expected active-passive difference (gen-

erally good performance on actives and bad on passives), the Wernicke's patients were inconsistent in this respect. As others have observed (Caramazza & Zurif, 1976; Grodzinsky, 1990), performance for this group cannot be predicted solely on the basis of syntactic factors.

Stimulus Materials

The experimental sentences consisted of 48 auditorily presented subject-relative constructions. To use our earlier illustration, the sentences were all of the form, "The gymnast loved the professor$_i$ from the northwestern city[1] who$_i$[2] (t_i) complained about the bad coffee." Again, by hypothesis, and as indicated by the subscript (i), the trace is assigned the thematic role (the role of "complainer" and "the professor" gets this role only indirectly-by being coindexed through the relative pronoun to the trace.

For each experimental sentence, a set of two words was created to be used as visual probes for the examination of priming. One of the words-the experimental probe-was semantically related to the moved constituent (the antecedent). The other word-the control probe-was unrelated to the antecedent. It was, however, matched to the experimental probe in frequency and length (Francis & Kucera, 1982). For the above example, the experimental probe was "teacher" (related to the antecedent, "professor") and the control probe was "address." The semantically related (experimental) probes were selected, in each instance, by combining data from published norms (Jenkins, 1970; Keppel & Strand, 1970; Postman, 1970) with data obtained by polling college-age and elderly adults for their first associates to the words that were later incorporated in the sentences as moved constituents.

As indicated by the superscripts 1 and 2 in the above example, priming was examined for each sentence at two points-at the gap indexed by the trace (superscript 2) and at a pregap position (superscript 1). We assessed priming at position 2 in order to measure whether the moved constituent was reactivated, or filled, at the gap (thus providing the prime). The pregap position (position 1) allowed us to measure any residual activation from the earlier appearance of the antecedent; that is, it enabled a baseline examination of any nonsyntactic priming effects. Of course, at each position priming was determined by comparing the lexical decision time for the experimental probe to that for the control probe.

Apparatus and Stimulus Construction

The sentences were presented auditorily on a Sharp Cassette Recorder (RD-771AV) with an internal tone decoder, the recording having been made by a female speaker, speaking at a normal rate. The letter-string probes were presented visually, appearing either on a Zenith 287 video monitor connected to a Protege 286 computer or on a Sony monitor (SSM-121) connected to a Compaq Portable II computer.

Coordination of the visual and auditory components for the experimental sentences was accomplished as follows: Each of the sentences was initially recorded on one channel only of a Teac reel-to-reel recorder. On another channel, for each sentence, a tone was placed to coincide with either the pregap position or the gap position. To place these tones, all sentences were digitized on a MAC II computer and examined visually as well as auditorily. [3] This material-the sentences and their associated tones-was then transferred to the stereo cassette. The tone for each sentence-inaudible to the subjects-served to trigger (via the tone decoder) the visual presentation of the letter-string probe so that the string appeared

[3] The digitizer with the MAC recorder eliminates frequencies over 17 kHz, which is well above the normal range of speech.

at the center of the monitor either at the offset of the word preceding the pregap position or at the offset of the relative pronoun ("who") preceding the gap position. The tone simultaneously initiated timing for the lexical decision. Subjects indicated their lexical decision using two response buttons which could be depressed using the index and middle fingers of their left hand. As soon as either button was depressed, the reaction time for that decision (in milliseconds) was recorded under software control, and the letter string was removed from the screen. If the subject did not respond within 2750 msec, the letter string was removed and that trial terminated.

RTLAB software (V9.0) controlled the experiment. With the aid of a software-accessible clock card (Metrobyte CIM05), RTLAB enables the synchronization of stimulus presentation with monitor raster position so that lexical decision timing is accurate beginning from stimulus onset.

Design

Two scripts were created. Each script contained one-half (i.e., 24) of the experimental subject-relative sentences and 101 filler sentences. Within each script, 12 of the 24 subject-relative constructions were presented in conjunction with visual probe words appearing at the gap, and 12 with visual probes presented at the pregap position. Six of the 12 gap probes in each script were experimental probes (letter strings forming words semantically related to the antecedent) and 6 were control probes. Likewise, 6 of the 12 pregap probes in each script were experimental and 6 control. Two versions of each script were prepared, the two differing from one another only in the matter of probe location-where one version contained a particular sentence with a gap probe, the other contained that sentence with the same probe at the pregap position.

Each subject was presented with *one* version of each of the *two* scripts. Thereby, as desired, each subject heard each of the 48 experimental subject-relative sentences *once only*. As a result, each subject contributed only one data point for any one sentence-one lexical decision time for either the experimental or the control probe in either the gap or the pregap position. Thus, across all 48 sentences, each patient contributed 12 data points per condition-12 reaction-time entries for the pregap experimental probe condition, 12 reaction-time entries for the pregap control probe condition, and the same number of entries for each of these two conditions at the gap location. Given this design, four subjects per aphasic group were necessary to satisfy both probe locations and to ensure that each experimental probe could be compared to its control. And with four subjects per group, each group generated 48 data points per condition.

As for the 101 filler sentences in each script, 38 were coupled with visually presented real words and 63 with visually presented pronounceable nonwords. These filler sentences were syntactically similar to the experimental sentences. But to diminish the possibility of a "position set," the visual probes associated with the filler sentences were placed at different positions from those associated with the experimental (subject-relative) sentences. [4]

Procedure

Subjects were tested individually in two sessions not more than 2 weeks apart, each lasting 45 min to 1 hr. They were fitted with headphones and seated at a table containing the video monitor and the lexical decision keys. They were instructed on both the auditory and the visual aspects of the task.

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[4] Actually, 24 of the 38 filler sentences coupled with real-word probes were target sentences for another experiment. But since this other experiment is irrelevant to the analysis presented here, they can be considered, for present purposes, as fillers.

With respect to the former, they were told that they would hear a series of sentences over the headphones and that their task was to listen carefully to each sentence. To encourage attention to the sentences, for each subject, we stopped the tape 14 times over the two sessions to ask a question about the sentence that was just presented. These questions did not bear on thematic assignment; ultimate interpretation of the sentences was not at issue. What was at issue was whether parsing was normal in respect to gap filling. Accordingly, we designed our questions only to reinforce the need for the subjects to listen to the sentences-using a multiple choice format, we asked only about the setting or general topic of a sentence (e.g., "Where did the activity occur-in a saloon? a classroom? or a police station?" or "Was the sentence about sports, music, or TV?") Indeed we did not even restrict the 14 questions of this sort to the experimental sentences; we also asked them of the filler sentences.

Subjects were also told that there would be a second, simultaneous task that they would have to perform: They would see a string of letters appear on the screen in front of them at some point during the presentation of each sentence, and they would have to decide as quickly and accurately as possible whether the letter string formed a word. They were instructed on the use of the response keys to indicate their decision-on pressing the "yes" key for a word and the "no" key for a nonword.

Each session consisted of 20 practice trials followed by the run-through of one version of one script.

RESULTS

Prior to a statistical analysis of the lexical decision times for the subject-relative constructions, a data screen was applied to remove errors and outliers. Errors consisted of trials on which the patients had incorrectly identified the probe words as nonwords and trials on which they had failed to respond within the maximum allotment of 2750 msec; they also included computer errors. Outliers were defined on an individual patient basis as reaction times that were more than two standard deviations above the subject's overall mean reaction time.[5] The frequencies of errors and outliers are presented in Table 1.

We cannot explain the somewhat lower error rate for the pregap experimental probes. We note, however, that the overall level of errors and outliers is of approximately the same magnitude as that observed in other reaction time studies (e.g., Prather et al., 1992; Shapiro & Levine, 1990).

The screened data for each subject in each condition were replaced by the subject's mean reaction time in each condition. The means of these screened data are presented in Table 2.

The individual reaction times for each subject in each cell were logarithmically transformed and then separately analyzed for the Broca's patients and the Wernicke's patients. For each group we performed two planned comparisons using the error term for a one-factor ANOVA. In one we compared experimental and control probe reaction times at the

[5] We also screened outliers on a three standard deviation criterion. Over all data entries for all subjects, this yielded only one less outlier than was found in the two standard deviation screen.

TABLE 1
Number of Errors and Outliers
(of 48 Entries per Cell)

	Pregap experimental		Pregap control		Gap experimental		Gap control	
	Errors	Outliers	Errors	Outliers	Errors	Outliers	Errors	Outliers
Wernicke's patients	2	3	8	1	9	0	5	2
Broca's patients	3	0	8	3	7	2	10	2

pregap position, and in the other, experimental and control probe reaction times at the gap site. Our use of planned comparisons was predicated on the consistent finding that priming for neurologically intact subjects is structurally governed-that is, that it occurs at gap sites and not at other locations. Indeed, we note that the 16 elderly neurologically intact subjects who were used to pretest the experimental sentences for this study (see footnote 2) also showed the expected structurally determined priming pattern: Their mean reaction times for the experimental and control probes, respectively, were 674 and 684 msec at the pregap position and 667 and 688 msec at the gap. The former comparison is not significant ($F < 1.0$), butthe latter is ($F(1,15) = 5.153$, $p = .038$).

With respect to the aphasic patients, the planned comparisons straightforwardly reveal that Wernicke's patients immediately filled gaps as they were encountered and that Broca's patients did not. To be sure, the Wernicke's patients' overall base reaction times are longer than those for the neurologically intact subjects-left-sided brain damage seems usually to lessen response speed in a nonspecific way (e.g., Swinney et al., 1989).

TABLE 2
Mean Reaction Times
(msecs)
Visual Probes

	Pregap experimental	Pregap control	Gap experimental	Gap control
Wernicke's patients	1017	1061	982*	1107*
Broca's patients	1145	1125	1126	1058

* Significant difference between reaction time for experimental probe and reaction time for control probe ($F(1,9) = 7.08$, $p = .026$).

But what is relevant to the assessment of gap filling is the priming pattern, not absolute reaction time. And in this respect, the Wernicke's patients appear normal. Specifically, the Wernicke's patient group showed significant priming for the experimental probes at the gap site ($F(1,9) = 7.08$, $p = .026$) but not at the pregap location ($F < 1.0$). By contrast, the Broca's patient group did not show priming for the experimental probes at either location (gap site: $F < 1.0$; pregap location: $F < 1.0$). [6]

DISCUSSION

Wernicke's aphasic patients show priming of antecedents at syntactically licensed gaps (indexed by traces). Our data, however, leave several questions unanswered concerning this phenomenon. Since all of our experimental sentences contained constituents that could plausibly fill the subject position, we cannot yet tell whether the patients must rely on such plausibility or whether, like normal subjects, they fill all potential gap sites regardless of plausibility (Swinney & Osterhout, 1990) and the site from which movement actually occurred (Hickok, Canseco-Gonzalez, Zurif, & Grimshaw, 1992). What we can conclude from the present data, however, is that Wernicke's patients show a normal sensitivity to structurally licensed gaps and that they automatically reactivate available constituents at these gaps-as sentences unfold in real time.

Does the reactivation of an antecedent at a gap indicate that the patient is assigning a thematic role to that antecedent? Or does this reactivation reflect the consequences of an earlier processing stage-a stage at which elements are coindexed and dependency relations estblished *prior* to thematic assignment? In the light of recent work by Shapiro and Levine (1990), the latter possibility appears much more likely. These investigators have shown that Wernicke's aphasic 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 lexical entry (Shapiro & Levine, 1990; Shapiro, Zurif, & Grimshaw, 1987, 1989). They are unable, that is, to generate a fully elaborated thematic grid (Carlson & Tanenhaus, 1987) in the normal manner. And this being so, it seems most reasonable to interpret the Wernicke's patients' ability to reactivate antecedents at gaps as being syntactically, not thematically, driven-as being the reflection of processing that occurs at a stage prior to thematic

[6] We emphasize that the Broca's patients' 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 protracted manner.

assignment (or mapping). Indeed, the fact that they were capable of filling gaps in subject-relative sentences for which they show uncertain comprehension (e.g., Grodzinsky, 1984) further strengthens this conclusion. (See also Hickok (1991) for the same interpretation of the gap-filling phenomenon based on studies of normal sentence processing.)

The conclusions we have drawn clearly do not provide a characterization of the role actually played by the cortical tissue implicated in Wernicke's aphasia. Still, we do provide a lower boundary on its functional commitment: whatever its role, it is not crucially involved in the real-time structural analysis required for the recognition and filling of gaps left by constituent movement.

By contrast, left anterior cortex-the cortical region usually implicated in Broca's aphasia-does appear to be necessary for the operation of gap filling. Contrary to Linebarger et al.'s (1983) speculations on the matter, our data show that Broca's patients do have a parsing problem-even for subject-relative sentences which they interpret at a level significantly above chance (e.g., Grodzinsky, 1986, 1989; Hickok, 1992). Either they are abnormally slow in linking antecedents and traces or they fail entirely to link the two. Either way, the consequences of this parsing problem seem relatively straightforward: Since they do not have the processing resources to establish dependency relations normally-to fill the gap at exactly the right time in the processing sequence-they cannot provide the syntactic representation necessary for supporting subsequent thematic assignment to moved constituents. Presumably, therefore, the Broca's patients rely abnormally on some nongrammatical strategy to achieve thematic role assignment for moved constituents-on a fill-in strategy (Hickok, 1992) or an agent-first strategy (Caplan & Futter, 1986; Grodzinsky, 1986). And when such strategies do not work, or when nonstructural length and complexity factors overwhelm their diminished resources,[7] their comprehension fails.

In effect, the parsing problem described here connects directly to previous analyses of the Broca's patients structural limitations. Our data indicate that these grammatical limitations are rooted to fairly elementary processing disruptions-specifically, to disruptions of automatic lexical reactivation (access) at the gap. In this view, the brain region implicated in Broca's aphasia is *not* the locus of syntactic representations per se. Rather, we suggest that this region provides processing resources that sustain one or more of the fixed operating characteristics of the lexical processing system-characteristics that are, in turn, necessary for build-

[7] We note, for example, that by increasing the number of main verbs in a sentence from one (the number standardly used) to two-by increasing length, in effect-even subject-relative constructions can be made difficult for Broca's aphasic patients to understand (Caplan & Hildebrandt, 1988).

ing syntactic representations in real time. Possibly these resources sustain the normal speed of lexical processing. This would be in line with independent evidence of slowed lexical processing in Broca's aphasia (Prather et al., 1993) and it is a possibility that we are currently exploring.

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