Neurological Distribution of Processing Resources Underlying Language Comprehension

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Abstract

Using a cross-modal lexical priming technique we provide an on-line examination of the ability of aphasic patients to construct syntactically licensed dependencies in real time. We show a distinct difference between Wernicke's and Broca's aphasic patients with respect to this form of syntactic processing: the Wernicke's patients link the elements of dependency relations in the same manner as do neurologically intact individuals; the Broca's patients show no evidence of such linkage. These findings indicate that the cerebral tissue implicated in Wernicke's aphasia is not crucial for recovering syntactically licensed structural dependencies, while that implicated in Broca's aphasia is. Moreover, additional considerations suggest that the latter region is not the locus of syntactic representations per se, but rather provides the resources that sustain the normal operating characteristics of the lexical processing system-characteristics that are, in turn, necessary for building syntactic representations in real time.

INTRODUCTION

The work presented in this paper seeks to advance our understanding of both sentence processing and functional neuroanatomy. In what follows, we link a syntactic comprehension failure to a neurologically localizable and elemental processing disruption. This work provides a basis for inferring how different brain regions normally serve aspects of sentence comprehension.

A relevant fact here is that the contrasting syndromes of Broca's aphasia and Wernicke's aphasia can be distinguished with respect to lesion site. The brain area associated with Broca's aphasia often involves the foot of the third frontal convolution (Broca's area) as well as adjacent and deeper areas (Alexander, Naeser, & Palumbo, 1990; Benson, 1985; Dronkers, Shapiro, Redfern, & Knight, 1992; Mohr, 1976; Naeser, Palumbo, Helm-Estabrooks, Stiassny-Eder, & Albert, 1989; Vignolo, 1988). Yet, notwithstanding the extent of this area, the modal lesion site for Broca's aphasia remains distinguishable from that for Wernicke's aphasia, where the associated lesion is typically inferior to the Sylvian fissure and mostly involves the superior temporal gyrus (Wernicke's area) (Benson, 1985; Vignolo, 1988).

The speech (output) patterns exhibited in these two syndromes are noticeably different from each other. Broca's patients present with nonfluent and telegraphic output; Wernicke's patients present with fluent, relatively empty speech (Goodglass & Kaplan, 1972).

The matter is more complex with respect to comprehension, however. Although both groups show a comprehension problem at the sentence level, particularly for complex sentences, the problem appears more focused on structural processing-more restricted to syntax-for Broca's than for Wernicke's patients. To be sure, there are claimed exceptions to this generalization. At least one reported Broca's patient demonstrates a comprehension pattern that appears to resist any kind of structural

interpretation (Badecker, Nathan, & Caramazza, 1991). Also, there are several case reports of patients with production impairments but no discernible sentence comprehension impairments (e.g., Miceli, Mazzucchi, Menn, & Goodglass, 1983; Kolk, Van Grunsven, & Keyser, 1985; Nespoulous et al., 1988). As a general point, however, the many Broca's patients who do show syntactically attributable sentence-level comprehension problems considerably outweigh those that have no such problem. Moreover, some of these exceptions may not even be Broca's aphasic patients to begin with; they seem exceptional even in terms of their output. For example, 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 the patient of Kolk et al. (1985). The importance of these exceptions is therefore unclear; they fail to fit the overall structure of accumulated evidence.

That the syntactic disruption is more clearly dominant in Broca's aphasia than in Wernicke's aphasia is revealed by the kinds of errors the patients make. In particular, on sentence picture matching tasks, Wernicke's patients often choose semantically inappropriate foils (e.g., Caramazza & Zurif, 1976; Heilman & Scholes, 1976), whereas Broca's patients' typically display syntactic errors affecting thematic role assignment-i.e., errors affecting the assignment of agent role and theme role (the person affected by an action) (e.g., Ansell & Flowers, 1982; Caplan & Futter, 1986; Caramazza & Zurif, 1976; Goodglass, 1968; Grodzinsky, 1986,1989; Hickock, Zurif, & Canseco-Gonzalez, 1993; Wulfeck, 1988).

Representational Considerations

Such assignment problems for Broca's aphasic patients are particularly noticeable for noncanonical sentence structures involving what are termed long-distance dependency relations. Consider for example, the sentence:

'THE OLD MAN SAW THE BOY THAT THE CROWD AT THE PARTY ACCUSED OF THE CRIME."

To interpret this object-relative sentence, the noun BOY must be understood to be the direct object of the verb ACCUSED, which in English canonically follows the verb. There are a number of representational accounts that characterize the displacement between direct object and verb found in this sentence. One of these, Government and Binding Theory (Chomsky, 1981), postulates, first, that the direct object is "moved" from its canonical position and, second, that a dependency relation exists between the new surface position of the direct object and the canonical site from which it was "extracted." A dependency of this type is traditionally represented by a "trace" in the extraction site (often called a "gap') that is coindexed to the "moved" constituent. This "trace" is a phonologically "empty" element employed as a placekeeper for the moved constituent. So, a representation for the above example is

"THE OLD MAN SAW *THE BOY*$_i$ THAT THE CROWD AT THE PARTY ACCUSED [*trace*$_i$] OF THE CRIME."

Within this framework, Grodzinsky (1986, 1990) and others (Hickok et al., 1993; Manner, Fromkin, & Cornell, 1993) have argued that the Broca's patients cannot represent traces and cannot, therefore, grammatically assign thematic roles (agent, theme, patient, etc.) to moved constituents. Faced 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 (as in the subject-relative sentence: "The *boy*$_i$ who [*trace*$_i$] pushes the girl is tall"), this agent-first strategy works; the strategy yields the same results as would normal grammatical processing. However, when movement is from object position (as in 'The *boy*$_i$ whom the girl pushes [*trace*$_i$] is tall"), the agent-first strategy yields two possible agents for the same sentence (one gets assigned correctly by role-marking indicators in the grammar, and the other incorrectly by this agent-first strategy). Therefore, on a sentence-picture matching test the patient must guess which of the two is correct, and this results in chance performance. Indeed, this characterization captures many reported observations in the literature-both for the subject-gap sentences that Broca's find relatively easy to understand and for the object-gap sentences that they most often interpret poorly (Ansell & Flowers, 1982; Caplan & Futter, 1986; Caramazza & Zurif, 1976; Goodglass, 1968; Grodzinsky, 1986; Hickock et al., 1993; Wulfeck, 1988).

Processing Considerations

To this point we have discussed attempts to describe the Broca's aphasic patients' comprehension problem along structural lines-specifically, in terms of their inability to capture intrasentential dependency relations. In what follows, we attempt to account for this syntactic problem as the reflection of a processing disruption-one that occurs at an early stage of information activation and integration. Crucially, we also expand our focus: we examine Wernicke's as well as Broca's aphasic patients for the purpose of determining whether the putative processing disruption at this stage is neurologically localizable.

The starting point for this inquiry is the consistently reported observation that Wernicke's aphasic patients have broadly normal automatic lexical access functions and that Broca's aphasics patients do not (Milberg & Blumstein, 1981; Milberg, Blumstein, & Dworetsky, 1987; Prather, Zurif, & Love, 1992; Prather, Shapiro, Zurif, & Swinney, 1991; Prather, Zurif, Stern, & Rosen, 1992; Swinney, Zurif, & Nicol, 1989). This observation stems from

studies of semantic priming during lexical access. Here, priming refers to facilitation in processing a word (the target) that appears immediately after a semantically related word (the prime). Activating the prime lowers the threshold for a semantically related target (e.g., Meyer, Schvaneveldt, & Ruddy, 1975; Neely, 1977).

The fact that Wernicke's patients show the normal pattern of faster word recognition in semantically facilitating contexts should not, however, be taken to indicate that these patients are entirely normal in accessing word meaning. That is, while these data suggest normal initial contact with lexical representations, they do not rule out the possibility of "coarse-coding" (Beeman et al., 1994) and therefore of a less-than-normally precise apprehension of a word's meaning. A rider must also be added to the observation about lexical priming in Broca's aphasia. Specifically, Broca's aphasic patients are not completely insensitive to priming relationships. Rather, for Broca's patients priming seems to be temporally protracted; lexical activation, as revealed by priming tasks, seems to involve a slower-than-normal time course (Friederici & Kilborn, 1989; Prather, Zurif, & Love, 1992; Prather, Zurif, Stern; & Rosen, 1992; Swinney et al., 1989).[1]

It is reasonable to postulate that slower-than-normal lexical activation will ramify throughout the comprehension system, affecting later structural and discourse processes that normally depend on the availability of information within a very narrow time frame. Guided by this possibility, we have focused particularly on how an impoverished lexical database might impinge upon the construction of dependency relations in real time-that is on linking moved constituents and their traces (a process termed "gap-filling') during the course of comprehension (Swinney & Fodor, 1989). This operation is implemented under strict time constraints, and, in light of the Broca's aphasics' slower-than-normal lexical activation, we sought to determine if their syntactic limitation-their failure to link moved constituents and their traces-could be viewed as an inability to reactivate the moved constituents at the normal time in the processing sequence.

Our first study of this possibility made use of sentences in which "movement" from subject position is hypothesized (see Haegeman, 1991, for the status of this hypothesis). We used subject relatives such as

"The man liked *the tailor*$_i$ with the British accent who (t_i) claimed to know the queen."

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 their lexical access characteristics, but also in their ability to understand the subject-relative construction. Broca's aphasic patients, as mentioned above, show relatively normal comprehension for this construction. Wernicke's patients, however, are unpredictable, more often than not showing chance comprehension (Grodzinsky, 1990; Shankweiler, personal communication, February 1992). So, for Broca's patients these sentences provided a clear test of our hypothesis: viz, that their slower-than-normal lexical activation would disallow the normal construction of syntactically governed dependency relations, even for sentences that they typically comprehend. For Wernicke's patients this study allowed us to determine the possibility of a reverse scenario-namely, that they could fill gaps even for sentences that they often fail to ultimately understand.

To these ends, our assessment of gap-filling made use of a methodology called cross-modal lexical priming (CMLP) (Swinney, Onifer, Prather, & Hirshkowitz, 1979). In this technique, subjects listen to an auditorily presented sentence and, while listening, make a lexical (word/nonword) decision to a visually presented letter string that is flashed briefly on a computer monitor while the auditory sentence is being presented. This technique has demonstrated that lexical decisions are facilitated for letter-strings forming words that are semantically related to just-previously-heard words. This priming is typically short-lived, and its measurement can be used to determine what words and concepts in a sentence are activated at any particular time during the processing of the sentence.

Using this technique we sought to discover whether priming for a word related to the putatively "moved" constituent would be found at the "gap" position-the position from which the constituent was extracted (Zurif, Swinney, Prather, Solomon, & Bushell, 1993; Zurif, Swinney, Prather, & Love, 1994). In this circumstance, priming would indicate that the moved constituent was, itself, "reactivated" at the gap/trace position, thereby serving as the prime. This effect has routinely been reported for normal processing using this and related experimental techniques (e.g., McElree & Bever, 1989; Garnsey, Tanenhaus, & Chapman, 1989; Nicol & Swinney, 1989; Nicol & Pickering, 1993.) So, in our initial investigation, aphasic patients were presented auditorially with subject-relative sentences of the sort exemplified earlier:

"The man liked *the tailor*$_i$ with the British accent^{*1} who (t_i)^{*2} claimed to know the queen."

There were two types of visually presented letter-string probes. One formed a word that was semantically related to the moved constituent (CLOTHES) and one formed a matched control word that was semantically unrelated to the moved constituent (WEIGHT). These were presented at the points indicated by the asterisk. Position *1 served as a baseline, allowing us to determine the amount of residual priming occasioned by the initial appearance (earlier in the sentence) of the moved constituent prior to the gap. Priming at position #2 served as the measure of "reactivation" of the moved constituent at the gap.

In these circumstances, Broca's patients did not show

priming at either baseline or gap positions. Thus, even for sentences that they appear to eventually understand, the normal real-time formation of a dependency relation is not demonstrated. Presumably, therefore, they are abnormally reliant on nongrammatical strategies for comprehending these sentences (Zurif et al., 1993).

By contrast, and in line with the performance of neurologically intact subjects, the Wernicke's patients did show reliable priming for probes related to moved constituents at gap (but not at baseline positions) (Zurif et al., 1993). While these results indicate that Wernicke's aphasics can form intrasentence dependency relations, even for sentences that they do not routinely understand, we note here that "movement" in subject-relative constructions has the special property of being 'string-vacuous'; that is, such movement does not reorder any of the elements of the sequence (Clements, McCloskey, Maling, & Zaenen, 1983). Indeed, it has even been argued (Chomsky, 1986) that there is no movement at all in such constructions, in which case the dependency relation we have charted here is not between a moved constituent and its trace but, rather, between a constituent and a relative pronoun (in the above example, between TAILOR and WHO).

Given this uncertainty, we undertook the present study to broaden the base of our observations of gap-filling in aphasia. To this end, we chose the object-relative construction-a construction for which constituent movement more clearly seems to be an optimal analysis than it is in the subject-relative case (Chomsky, 1986; Haegeman, 1991). The object-relative sentences that we used were of the type

"THE PRIEST ENJOYED *THE DRINK*$_i$ THAT THE CATERER WAS^{*1} SERVING (t_i)^{*2} TO THE GUESTS."

As in our earlier study employing subject-relative constructions, we used the CMLP task and examined for priming both at the baseline (*1) and gap (*2) positions. For the example given, WINE was the semantically related "probe" for "drink," and BOAT was the control probe.

In light of the Broca's patients' failure to fill gaps for subject-relatives (sentences they understand), we did not expect that they would show gap-filling for object relatives (sentences they fail to understand). We did, however, have more positive expectations for Wernicke's patients. Given their broadly normal initial activation of the lexicon and their ability to form dependency relations (of whatever sort) in subject relatives, we fully expected them to fill gaps in object relatives. That is, we expected that the real-time formation of intrasentence dependency relations could be revealed as an isolable stage of sentence processing independent from ultimate levels of sentence comprehension. To assess these possibilities, we tested four Broca's aphasic patients and four Wernicke's aphasic patients-patients who demonstrated the expected pattern of lesion site and behavior associated with their respective syndromes.[2]

RESULTS

Statistical analysis performed on the reaction time data gathered in this experiment demonstrate a clear difference between the two aphasic populations in terms of reactivation of the moved constituent (direct object) at the gap site following the verb. This difference can be seen in Table 1, which displays mean reaction times for "related" and "control" probe words for the experimental sentences. The data are displayed separately for the baseline (*1) condition and the canonical (*2) postverb position. Prior to analysis these data were screened for outliers with a 2 standard-deviation screen. For each data point removed via this screen, its "matched" counterpart (either the related or control "probe') was also removed. Together, all omitted responses and screened outliers constituted 13% of the total number of trials. These data points were dropped from further analysis. Planned comparisons were then carried out separately for each subject group. These comparisons were performed between data from "related" and "control" conditions (examining for priming) at the baseline (*1) position and separately at the gap (postverb;*2) position. Our use of planned

Table 1. Mean Reaction Time Responses (in Milliseconds) for "Related" and "Control" Probes at Baseline (*1) and Gap (*2) Positions for Broca's and Wernicke's Aphasic Subjects

Probe position	*Baseline- *1*	*Gap-*2*
Broca's Aphasic patients		
Related probe	1257	1183
Control probe	1379	1174
Wernicke's Aphasic patients		
Related probe	1511	1378
Control probe	1514	1486

comparisons was predicated on the consistent finding already emphasized in this report, namely, that priming for neurologically intact subjects is structurally governed-that is, that it occurs at gap sites and not at other locations. And indeed, we note that the 20 elderly neurologically intact subjects who were used to pretest the experimental sentences for this study (see note 2) also showed the expected structurally determined priming pattern: their mean reaction times for the related and control probes, respectively, were 784 and 791 msec at the baseline (pregap) position and 766 and 809 msec at the gap. The related-control difference at the baseline is not significant ($F < 1.0$, $MSe = 3682$) but the difference at the gap is significant [$F(1,19) = 5.740$, $p < 0.03$, $MSe = 3197$] (Zurif, Swinney, Prather, Wingfield, & Brownell, 1996).

For the Broca's aphasic patients, the related vs. control planned comparison (priming) for the Baseline Position was not significant [$F(1,3) = 1.287$, $p = 0.34$, $MSe = 23202$] nor was that for the Gap Position [$F(1,3) = 0.052$, $p = 0.84$, $MSe = 3144$]. It can be noted, however, that some advantage for the related probes appears to exist at the baseline position. In effect, while for this group there was no sign of structurally determined reactivation of the moved constituent at the gap, there was some sign of residual activation before the gap (likely due to the processing of the initial appearance of the constituent in a "slowed" fashion).

For the Wernicke's aphasic patients, the data were well aligned with data reported for neurologically intact populations [see, e.g., Swinney and Fodor (1989) for reviews of this literature]. Specifically, the related vs. control planned comparison for the Baseline Position was not significant [$F(1,3) = 0.0001$, $p = 0.99$, $MSe = 67662$], but that for the gap position was significant [$F(1,3) = 23.663$, $p = 0.017$, $MSe = 997$].

DISCUSSION

Some general points concerning the Broca's-Wernicke's difference: First, we note that this difference cannot be attributed to different levels of comprehension ability. The fact that the Wernicke's patients, but not the Broca's, filled gaps is not accountable by better comprehension-by closer-to-normal comprehension-in the Wernicke's. In fact, as can be seen in the Methods section (where comprehension scores are entered for each patient), the Wernicke's patients tended to perform at a lower comprehension level than did the Broca's. So from this perspective, the groups seem to differ qualitatively, not quantitatively along some "severity" dimension.

Nor can this group difference be reduced to one of statistical power. To be sure, MSe's show the Broca's patients as a group to be somewhat more variable than the Wernicke's patients as a group at the gap position. However, this difference must be placed in the context of the overall result pattern: Whereas the Wernicke's patients showed a significant advantage for related probes solely at the gap site, for the Broca's patients the only sign of an advantage for related probes was at the pregap site. In effect, while the former showed structurally governed *and normally rapid* reactivation, the latter showed the opposite pattern of a nonstructurally determined residual activation-an effect attributable to *slower-than-normal* processing.

Finally in this general vein, we emphasize that the Broca-Wernicke difference with respect to gap-filling has now emerged in two studies and correspondingly across two distinctly different sentence types. On balance, then, there seems to be a genuine syndrome-based difference that brackets the real-time operation of a particular processing stage in the service of comprehension.

Wernicke's Aphasia and Functional Localization

We are only beginning to characterize the functional commitment of the brain tissue associated with Wernicke's aphasia. Our data show that lesions to this area do not foreclose the capacity to construct intrasentence dependency relations. But we have yet to determine how structurally precise this processing reflex is, that is, we have yet to determine if Wernicke's patients reactivate *only* structurally appropriate constituents at gaps or if they reactivate any available constituent, appropriate or not. At present, then, we can conclude only that the brain region implicated in Wernicke's aphasia is not crucial for the underpinnings of this syntactic reflex-that is for recognizing and filling gaps in real time.

It is instructive that the Wernicke's ability to fill gaps occurs even in the face of poor sentence comprehension. This fact suggests that dependency relations of the sort measured here are normally constructed at a rather early stage of sentence processing, before representing thematic relations of the sort, "who (agent) does what to whom (theme)." This notion is furthered by considering our data alongside findings reported by Shapiro and his colleagues (Shapiro, Zurif, & Grimshaw, 1987, 1989; Shapiro & Levine, 1990; Shapiro, Gordon, Hack, & Killackey, 1993). These investigators have shown via on-line measurements that Wernicke's patients are insensitive to the argument-taking properties of verbs during comprehension. Unlike neurologically intact subjects, Wernicke's patients cannot access momentarily all of the possible argument structure configurations within a verb's entry-configurations consisting of agent, theme, goal, and the like. That is, they are unable 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. That is, it seems to reflect a processing stage prior to the full availability of

a verb's argument structure and prior to thematic role assignment-and a processing stage that does not fully depend upon the integrity of Wernicke's area.

Broca's Aphasia and Functional Localization

By contrast, the brain region implicated in Broca's aphasia does appear to be necessary for this operation of syntactically governed reactivation. Our data show that Broca's aphasic patients do not construct syntactic representations normally in real time. Presumably, therefore, they must rely on other processes to achieve the level of comprehension they show in conversational settings. Such processes seem likely to involve linear-based strategies [such as the agent-first strategy (e.g., Grodzinsky, 1986)] and the use of semantic and/or pragmatic cues (and, indeed, the experimental sentences used in this study provided such cues).

At any rate, the structural disruption observed here for Broca's patients can be rooted to a more elemental disruption of automatic lexical activation-viz., a slowing gf lexical activation in both sentence and nonsentence contexts, a slowing revealed by temporal priming patterns, not absolute reaction times (e.g., Prather, Zurif, & Love, 1992). What we have shown here is the way in which this problem ramifies to the syntactic level. In the view we have developed, the brain region implicated in Broca's aphasia is not the locus of syntactic representations per se, but rather, appears to provide the resources that sustain the normal timing characteristics of the lexical processing system-characteristics that are in turn necessary for building syntactic representations in real time.

Possibly this brain region has other functional commitments that also impact upon syntactic processing. For example, the area associated with Broca's aphasia might also accommodate the memory storage requirements for forming dependency relations. Or perhaps memory limitations following lesions to this area are epiphenomenal-perhaps slower-than-normal lexical activation simply taxes memory capacity more than is usual. Or possibly the time alteration is, itself, the reflection of a more basic aberration of lexical activation-an aberration to be described in terms of activation *level* (Milberg, Blumstein, Katz, Gershberg, & Brown, 1996).

All of these possibilities, however, are variations on the same theme: they all suggest that syntactic limitations are linked to changes in a cortically localizable processing resource. Accordingly, we propose that neurological specialization within the language system turns not on where different general knowledge sources (e.g., syntax, semantics) are localized, but rather on the anatomical distribution of fairly elemental processing resources such as those involved in lexical activation.

METHODS

Subjects

We tested four Broca's aphasic patients and four Wernicke's aphasic patients in this work. The Broca's patients ranged in age from 59 to 77 years and all had at least a high school education. The Wernicke's patients ranged in age from 57 to 69 years; three had a high school education and one had schooling through the ninth grade. In each case, diagnosis was based on the convergence of clinical consensus and the results of a standardized aphasia examination-the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1972). At the time of testing, all had retained the defining features of their original diagnosis. The four Broca's patients still presented with nonfluent and telegraphic verbal output and with relative sparing of auditory comprehension at the conversational level. In contrast, the four Wernicke's patients still had fluent, relatively empty speech and tended to show more comprehension problems than did the Broca's patients.

In what follows we briefly present the available neuroradiological (CT scan) findings for each patient. We also provide, with one exception (RD), each patient's score on a sentence-picture matching test of object-relative sentence comprehension. (The 10 object-relative sentences included in this "off-line" test were of the sort used in our on-line test of gap-filling.)

Broca's Aphasic Patients

RD had two left CVAs-one in 1976 and a second in 1977. A CT scan taken in 1978 indicates two lesions, one in Broca's area with deep extension to left frontal horn and involving lower motor cortex (face and lip regions) and the other in the left temporal lobe sparing most of Wernicke's area but encompassing the *anterior* portion of Brodmann's area 22 [an area implicated in Broca's aphasia by Dronkers, Wilkin, Van Valin, Redfern, & Jaeger (1994)]. As noted above, RD was the only patient who did not receive our object-relative sentence comprehension test. This was because his comprehension had just been extensively examined in another study (Hickok, et al., 1993). As reported in the write-up of this study, the patient scored at the 35 and 37% levels on two separate measures of comprehension for object-gap constructions.

FC suffered a left CVA in 1973. His CT scan shows a very large left dorsolateral frontal lobe lesion involving almost all of the inferior and middle frontal gyri, including all of Broca's area and the white matter deep to Broca's area. The lesion continues superiorally and includes the lower two-thirds of the premotor, motor, and sensory cortex and the white matter deep to these areas. There is no lesion in the temporal and parietal lobules. Although in the fashion of most Broca's patients he

showed generally poor comprehension for object-gap constructions (e.g., 40% correct for passives), he did very well on our 10-item assessment of object-relative constructions (90% success). And we have no explanation for this.

WS suffered a left MCA infarct in 1988. A CT scan performed in 1989 shows a lesion present in the anterior insular area with deep extension toward the head of the caudate, including anterior portions of the claustrum and putamen. There is a superior lesion extension into portions of the middle frontal gyrus, all of the motor/sensory cortex areas for the mouth and most of the supramarginal gyrus, but only a small portion of the angular gyrus. This frontoparietal lesion extends deep into subcortical white matter at the level of the bodies of the lateral ventricle and includes most of the anterior third and middle third of the periventricular white matter. But no lesion is present in Wernicke's area or in the temporal isthmus area. On the comprehension test he scored at the 50% level.

RB, as revealed by CT scan, has a large lesion in Broca's area with two deep extensions involving the subcallosal fascictilus and insular structures. There is also some superior extension to the supramarginal gyrus and the angular gyrus. He comprehended the object-relative sentences on our test exceptionally well-at the 90% level. However, he consistently asked to have these object-relative sentences repeated-at least three or four times for each of the 10 sentences. Also he appeared extremely unsure of his answers. And these aspects of his performance were in stark contrast to the way in which he responded to active and subject-gap sentences. For these latter sentences he responded almost immediately and with extreme confidence. We think this pattern is instructive in light of our on-line analysis of comprehension. Our on-line data indicate that the Broca's problem is not due to a lack of syntactic knowledge but to an inability to implement this knowledge in real-time. Granting this, a comprehension failure for any one sentence need not be immutable. Rather, as suggested by RB's performance, comprehension for that sentence might build up "incrementally"-in the sense, say, that the patient learns, over several repetitions, the inutility of continuing to apply an agent-first strategy for an object-gap construction.

Wernicke's Aphasic Patients

CC suffered a left CVA in 1984 and a CT scan performed later that year indicates 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 and a second in the occipital lobe. He scored at the 80% comprehension level for objective relative constructions on our sentence-picture matching test.

JM's left CVA occurred in 1986 and a CT scan taken later that year shows a vague patchy lesion involving the temporal isthmus, which has been interpreted as interrupting the auditory fibers from the medial geniculate nucleus before reaching Heschl's gyrus and Wernicke's area. The patchy lesion extends superiorly into the posterior supramarginal and angular gyrus areas with deep extension to the border of the left lateral ventricle. JM comprehended only 20% of the object relatives on our sentence-picture-matching test.

WD suffered a left CVA in 1991 and a CT scan done later that year shows a lesion in the posterior half of Wernicke's area, continuing into the supramarginal gyrus and angular gyrus. His comprehension score for object relatives is 40%.

NL shows, on a CT scan performed in 1987, a low attenuation region in the left posterior temperoparietal region with no other areas of involvement. He scored 50% comprehension for object relatives on the sentence-picture-matching test.

We note, in summary, a general feature of these patient profiles. The Broca's patients all have left-sided prerolandic lesions. As is common, the damage is clearly not restricted to this region, although it does skirt Wernicke's area. By contrast, all of our Wernicke's patients have only posterior lesions, these involving mostly the temporal lobe (including Wernicke's area). These neuroradiological patterns broadly conform to current views of lesion localization (Benson, 1985; Vignolo, 1988).

Materials

A script of 48 experimental and 72 "filler" sentences was created for auditory presentation. The experimental sentences consisted of object relative constructions as in our earlier illustration: "THE PRIEST ENJOYED THE DRINK, THAT THE CATERER WAS* [1] SERVING (t) * [2] TO THE GUESTS." "Related" and "control" probes for each sentence were chosen as follows: the former were semantically related to the putatively "moved" constituent (WINE in our example) and the latter were semantically unrelated to anything in the sentence, but matched for frequency and length and a priori lexical decision reaction times with the semantically related probe word (BOAT for our example sentence). (A priori base reaction times were recorded for these words when presented one at a time in isolation from any sentential material.) Thus, any reaction time difference found between the semantically related and control probe words during ongoing sentence processing can be attributed to effects caused by the processing (or reprocessing and reactivation) of words in the sentence. [3] See the Appendix for a list of the experimental sentences and their associated probes.

All sentences were digitized at 22K samples per second. Probe-appearance location markers, in the form of

a 1/4-sec 1K-Hz pulse tone, were then recorded (via digital techniques) for all sentences. These pulses served to trigger occurrence of the visual letter string (a probe) in the center of a display monitor. Simultaneously with the appearance of the visual letter string, timing functions were initiated to record lexical decisions. For the experimental sentences, the probe appearance markers occurred at two possible locations: (1) the baseline position, which was just before the verb from which the direct object had been "moved" and (2) the gap position just after that verb. These positions are indicated by the numbered asterisks in the sample sentence. For the filler sentences, there was a single probe location that occurred at a randomly chosen location (distributed evenly across first, middle, and last thirds of the sentences).

The script was formed by recording the digitized sentence and probe-location pulses to a tape. The sentences were recorded to one channel of the tape, and the probe-location pulses to the other. (In the experiment, the subjects could not hear the probe location pulses.) Filler sentences were randomly interspersed among the experimental sentences to create a script. Two such scripts were created so as to ensure that for any one experimental sentence any single script tape contained only the baseline or the postverb ("gap') probe-location pulse. There were equal numbers of these in each script.

Two experimental lists of probe words were created to use with these sentences. Semantically related and control probes were equally distributed among the two lists. Probes for 60 of the filler sentences constituted orthographically legal nonwords, the remaining 12 were real words. Thus, throughout the experiment every subject heard 60 sentences for which a real word appeared somewhere as a probe and 60 sentences for which a nonword appeared as a probe. Each subject on each visit participated in only one of the resulting 4 experimental conditions (2 scripts x 2 lists), and thus heard each experimental sentence only one time, paired with only one of the 2 probe words for that sentence. Subjects were tested in four sessions generally lasting an hour each, featuring frequent rests. Sessions were separated by a minimum of one month.

Procedure

Our experimental examination of the reactivation of "moved" constituents employed a cross-modal-lexical-priming technique in which subjects listened to each auditorily presented sentence presented uninterruptedly and at a normal speaking rate. Subjects were required to comprehend this sentence and comprehension was tested several times throughout the experiment (largely to reinforce the need for subjects to pay attention to the content of each sentence). While listening to each of these sentences, subjects were also required to make a word/nonword (lexical) decision to its paired, briefly presented, visual letter string. This technique has been shown to reflect precisely when a word in a sentence is "activated" or processed during the comprehension of that sentence. All stimulus presentation and timing were under software control of the program RT LAB v9.0, which employs a separate software-accessible clock that enables the synchronization of stimulus presentation with monitor raster position so that the lexical decision times are accurate beginning from stimulus onset.

Subjects were instructed in both the visual and auditory aspects of the experiment, and prior to the experiment itself, demonstrated the ability to make lexical decisions accurately in the context of listening to sentences. Subjects indicated their lexical decision using two response buttons, which could be depressed using the index and middle fingers of their left hand. One button was labeled YES to indicate a word and the other was labeled NO to indicate a nonword. When the YES button was pressed, a high pitched tone occurred (which served as reinforcement to the subjects and indicated to them they had indeed responded 'yes'). Pressing the NO button resulted in a low-pitched tone reinforcer. The subjects rested one finger on each button throughout the experiment, and as soon as they depressed either button, the letter string disappeared from view and the reaction time for that decision in milliseconds was recorded by the computer. If the subject did not respond within 2750 msec, the letter string was removed and that trial terminated.

Appendix: Experimental Sentences and Associated Probes

The police stopped the boy that the couple had accused of the crime.
girl body
The old woman picked up the apple that the girl had thrown in the gutter.
fruit bench
The worker repaired the truck that the donkey had kicked in the fender.
van net
The woman smelled the rose that the manager had picked for the bouquet.
thorn louse
The judge convicted the thief that the usher had caught with the money.
crook tribe
The baby ate the bread that the bird had dropped by the fence.
crust snail
The waiter found the ring that the caddy had lost on the fairway.
gold seat

The officer found the brick that the kids had thrown at the house.
clay film

The bird ate the fish that the waves had washed onto the shore.
trout spice

The tailor hemmed the cloak that the Broadway actor needed for the performance.
robe goat

The hunters trapped the deer that the hounds had chased into the cave.
moose mask

Lightening struck the house that the tall trees were protecting from the wind.
home well

The teacher caught the snake that the principal had seen near the barn.
reptile booklet

The teacher recognized the shirt that the custodian had stolen from the old woman.
pants bean

The seamstress had designed the suit that the handsome jockey tore during the race.
dress chair

The sheriff impounded the car that the bartender had sold to the body shop.
jeep dish

The pianist played the song that the mayor had heard at the wedding.
tune coin

The union leader addressed the woman that the supervisor had fired after the strike.
female prison

The woman cleaned up the mud that the children had brought into the house.
dirt coat

The doctor treated the tourist that the lion had bitten on the hand.
trip court

The waiter cleaned up the milk that the teenager had spilled on the tablecloth.
cream tooth

The farmer sold the fruit that the squirrel had knocked from the tree.
pear cord

The jogger saw the accident that the bad weather had caused yesterday morning.
crash crate

The lifeguard kicked the box that the guide had left on the beach.
carton coupon

The priest enjoyed the drink that the caterer was serving to the guests.
wine boat

The statesman lit the pipe that the ambassador had sent as a gift.
smoke bread

The girl found the pottery that the Indians had made many years ago.
bowl plug

The scientist removed the rats that the hawk was watching with great interest.
mice doll

The lady removed the branches that the wind had ripped from the trees.
twig ram

The student bought the book that the lecturer had recommended the year before.
novel rifle

The old woman watched the parade that the promoter had planned so thoroughly.
march visit

The ranger cooked the food that the locals had brought as a gift.
meat cast

The youth delivered the letter that the intern had written for the boss.
mail bond

The forest service rescued the hikers that the balloonist had spotted near the river.
climbers drummers

The audience liked the wrestler that the parish priest condemned for foul language.
fighter cleaner

The people cheered for the athlete that the sports commentator praised for his speed and agility.
runner garment

The director watched the skater that the dancer had insulted out of sheer jealousy.
ice cup

The actress congratulated the singer that the audience had honored with a standing ovation.
tune mice

The receptionist greeted the dignitary that her boss had described in great detail.
famous active

The widow called the merchant that her cousin had recommended for his honesty.
business question

The bellhop delivered the telegram that the guests were expecting for a week.
message lawyer

The cyclist fixed the light that the motorist had hit with his van.
bulb lamb

The gentleman tasted the wine that the hostess had poured from the old bottle.
alcohol nursery

The busboy pocketed the coins that the customer had left on the table.
wallet peanut

The man caught the fish that the Indian had speared in the belly.
scale tool

The woman read the note that her landlord had left or the door.

card disk

The corporal wrote on the paper that the cadet had brought to the office.

pencil branch

The therapist examined the leg that the kicker had injured in the big game.

foot boat

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Notes

1. Ostrin and Tyler (1993) express a contrary opinion. They claim that Broca's aphasic patients can carry out normally rapid automatic lexical activation. However, this claim is based on their use of a word-pair presentation paradigm. When such a paradigm is used without any distracting manipulations (see Neely, 1977, for discussion) strategic (controlled) processing is often seen to dominate. Setting words together in pairs appears to foster expectations, guessing, and checking strategies that are not obvious components of normal automatic sentence processing (see Shelton & Martin, 1992; Prather, 1996, for further discussion).

2. We also assessed gap-filling in 20 neurologically intact subjects of roughly the same age as the aphasic patients (Zurif. Swinney, Prather, Wingfield, & Brownell, 1996). The sentences used for this assessment were exactly the same as those used for the present study; in fact, the neurologically intact subjects were used to pretest the sentences.

3. The use of this approach for establishing baselines (and alternative approaches) is discussed in detail in Nicol, Fodor, and Swinney (1994; see also McKoon, Ratcliff, & Ward, 1994). As is explained in detail there, this method is deemed to be ultimately preferable to the other possible approaches as an a priori equating measure, as it holds the sentences (which have large variability) constant in such experiments.

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