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Chapter 13
Brain Regions of Relevance to Syntactic Processing

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This chapter discusses aphasia research, that is, research on language disorders resulting from focal brain damage. The aim is to provide a view of how parts of the sentence comprehension system are neurologically organized. To this end, a description will be offered of how the failure to represent particular forms of syntactic information can be traced to processing disruptions that can be localized in the brain. This will provide a basis for inferring how different brain regions normally serve syntactic analysis during comprehension.

13.1 The Clinical Material

The studies that illuminate this neurologically based functional architecture build upon clinical descriptions first provided in the 1870s, at the start of the modem era of aphasia research (e.g., Wernicke 1874/1977). These "classical" descriptions have it that there are two kinds of language failure and that each can be related to a specific region of brain damage.

One kind, now called Broca's aphasia, clinically appears as an output problem. That is, comprehension is relatively normal; but speech is nonfluent, syntactically limited, and "agrammatic" such that grammatical morphemes, both bound and free, tend to be omitted. This aphasia is generally associated with damage to the left frontal lobe of the brain. And this includes a region in the third frontal convolution referred to as Broca's area—namely, that portion of the cortex in front of the primary motor zone for the muscles serving speech (Goodglass and Kaplan 1972).

The second kind of aphasia, now termed Wernicke's aphasia, is characterized by fluent and effortless speech, with phrasal construction appearing to be largely intact. But speech in this syndrome tends to be empty,

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marked by the use of vague filler words ("thing" and "this" and "that"). Also, comprehension is usually noticeably impaired. This aphasia results from damage to the posterior region of the left hemisphere—particularly to Wernicke's area, an area in the superior temporal gyrus adjacent to the cortical region involved in hearing (e.g., Goodglass and Kaplan 1972).

It will be noted that these descriptions emphasize the distinction between speaking and comprehension and that this emphasis has commonsense force and a certain clinical reality. But these classical descriptions have turned out to be seriously incomplete. As will be shown in this chapter, a fuller understanding of the aphasias—indeed of brain-language relations generally—requires reference not only to the observable activities of speaking and listening, but also to abstract linguistic structures and processes.

Before elaborating on this claim, however, a neurological update is in order: The brain area involved in Broca's aphasia now seems to have greater extent than initially proposed. Broca's area in the third frontal convolution is no longer considered to be singularly important; rather, adjacent and deeper areas have also been implicated (e.g., Naeser et al. 1989). Still, the fact remains that the modal lesion site for Broca's aphasia is clearly distinguishable from that for Wemicke's aphasia, where, in line with early descriptions, the greatest involvement is still considered to be in the superior temporal gyrus. In brief, each of these two aphasias still has brain localizing value—a fact that must be borne in mind throughout the remainder of this chapter.

13.2 Sentences That Aphasic Patients Have Difficulty Understanding

13.2.1 Some Initial Characterizations

Although for many years, descriptions of Broca's aphasia emphasized the output disorder, it was, nonetheless, recognized that comprehension, too, was not entirely normal. As earlier noted, the working phrase was always *"relatively* normal" comprehension; however, the results of a series of experiments in the 1970s and 1980s belied even this characterization (e.g., Caplan and Futter 1986; Caramazza and Zurif 1976; Zurif, Caramazza, and Myerson 1972; and see Grodzinsky 1990 for a review). By assessing comprehension via sentence-picture matching tests (the patient hears a sentence and chooses its correct depiction), comprehension in Broca's aphasia was observed to be relatively limited, not relatively normal.

Two general patterns emerged from this work in the 1970s and 1980s. The first had to do with word-order relations within a sentence. This pattern can be illustrated by the contrasting sentence: "It was the girl who

chased the boy" and "It was the boy whom the girl chased." In both sentences the girl is causing the event to unfold and is thereby assigned the role of agent of the action. The boy is the person affected by the action in both sentences; he is assigned in each case what is termed the role of theme. What differentiates the two sentences is the order of mention of the participants involved in the activity. In the first sentence—referred to as a subject-cleft construction—the first participant encountered is the agent; in the second sentence—referred to as an object-cleft construction —the theme is the first encountered. This difference is crucial. In English sentences it is much more usual for agents to appear in first position, and themes in second. In other words, the agent-first position is the canonical position in English syntax. And, directly to the point of this chapter, Broca's patients showed good comprehension for sentences containing this order—for sentences such as subject-clefts. By contrast, when canonical order was violated, as in object-cleft sentences, the Broca's patients performed poorly on the sentence-picture matching tests.

The second comprehension pattern turned on whether or not semantic and/or plausibility cues were present in sentences. By systematically manipulating the availability of such cues, the studies in the 1970s and 1980s documented that Broca's patients could understand sentences even with complicated (noncanonical) syntax when plausibility considerations supported "educated guesses." So, they could understand "It was the mouse that the cat chased;" but, as mentioned earlier, they could not understand "It was the boy whom the girl chased." Both are noncanonical (object-cleft) sentences; the first, however, constrains guessing in a way that the second does not—mice rarely chase cats, but boys are as likely to chase girls, as girls, boys.

These result patterns have held up reasonably well over the years. Although exceptions have been observed, it remains a fairly solid generalization that in the absence of plausibility constraints, Broca's patients show better comprehension for canonical, agent-first sequences than for noncanonical sequences (e.g., Caplan and Hildebrandt 1988; Grodzinsky 1990).

Comparable analyses have not appeared for Wernicke's patients—and probably not by chance. Although Wernicke's patients also seem to have considerable difficulty understanding noncanonical constructions, their comprehension" problem seems less syntactically focused than it is for Broca's patients; it seems to require also a consideration of semantic factors. For example, faced with "It was the boy whom the girl chased," Wemicke's patients are as likely to point incorrectly to the depiction of a girl hitting, as opposed to chasing, a boy as they are to confuse agent and theme (in the manner of Broca's patients).

As it happens, this difference between Wemicke's and Broca's has lately figured importantly in thinking about brain-language relations from a real-time processing perspective. To make sense of this perspective, however, we first need to consider the Broca's syntactic limitation on its own. This follows.

13.2.2 The Extent of the Syntactic Breakdown in Broca's Aphasia

The initial accounts held that no syntactic capacities at all are retained in Broca's aphasia, other, that is, than the ability to identify lexical categories (nouns and verbs) (e.g., Caramazza and Zurif 1976). In this view, in the absence of any semantic and/or plausibility constraints, the patients were seen to rely solely on the nongrammatical strategy of assigning thematic roles—agent, theme, goal, and the like—to linear strings of nouns and verbs. More specifically, it was hypothesized that the Broca's patients could bank only on the usual, or canonical, agent-first position—that is, they could rely only on the strategy of assigning agency to the first encountered noun in a sentence. This worked in most cases, but not always—not, for instance, for object-cleft sentences in which the first noun is the theme, not the agent. (Again, in "It was the boy whom the girl chased," the first N ("boy") is the person chased, not the person chasing.)

This characterization of Broca's having no syntactic capacity at all now, however, seems too harsh. The argument against it turns on error patterns. Specifically, it tums on the fact that Broca's patients are very rarely 100 percent wrong—or even significantly below chance—for sentences such as object-clefts, where the first noun is not an agent (Caplan and Futter 1986; Caramazza and Zurif 1976; Grodzinsky 1986; Wulfeck 1988). But with no syntax available to the patient, with thematic assignment rooted to the agent-first strategy, the Broca's patient would be expected *always* to interpret object-clefts backwards (regarding who chased whom); they would not be expected ever to perform at the roughly chance level that is most typically observed. In effect, the agent-first strategy does not seem to be the only determinant of sentence comprehension; there seems to be some opposing force.

13.2.3 The Trace Deletion Hypothesis

This notion of competing forces is at the heart of a descriptive generalization formulated by Yosef Grodzinsky (1986, 1990) and much discussed in the recent literature. His account is grounded in *government-binding theory* (Chomsky 1981), wherein movement of a constituent leaves a trace (an abstract, phonetically empty marker) in the position it vacated. As described elsewhere in this volume, traces are deemed crucial for the assignment of thematic roles in sentences, since these roles are assigned to

hierarchically structured positions regardless of the assignee. If a thematic position is filled with a lexical NP, then it receives its thematic role directly. But if a thematic position contains a trace, then the trace is assigned the thematic role and the moved constituent (the antecedent) that left the trace gets its role only indirectly, by being coindexed to the trace.

Grodzinsky's characterization of the comprehension limitation in Broca's aphasia is that, although patients of this type appreciate hierarchical syntactic organization, they cannot represent traces and, therefore, cannot grammatically assign thematic roles to moved constituents. Faced with a thematically unassigned noun phrase, the Broca's patient applies the above-mentioned agent-first strategy. But in contrast to the earlier accounts, Grodzinsky's claim is that this strategy is applied in the context of an otherwise normally elaborated syntactic representation.

How Grodzinsky's analysis works can be illustrated by referring again to the cleft sentences, this time to their abstract linguistic representations. Consider first the object-cleft construction. Its representation can be approximated as follows: "It was the boy,- whom the girl chased $(t)_i$." (The vacated slot, or gap, in the object position of the verb "chased" is indicated by the trace (f); and the coindexation of the moved constituent and the trace is shown by the subscript *(i).)* Normally, the moved constituent "the boy" is assigned the role of theme via coindexation. But Broca's patients cannot represent the trace and cannot, therefore, grammatically assign any role to "the boy." Accordingly, the patients adopt the agent-first default strategy, but by Grodzinsky's reasoning this sets in motion competing thematic assignments: Specifically, the incorrect strategic assignment of agency to the moved constituent ("the boy") is countered by the normal grammatical assignment of agency to the constituent that has not undergone movement ("the girl"). Faced with two agents (on a sentence-picture matching task), the patient is forced into a guessing situation that leads to random performance, as opposed to a systematic inversion of thematic roles.

Consider now the linguistic representation of the subject-cleft: "It was the girl,- who (f); chased the boy." Here "the boy" has not undergone movement, and movement of "the girl" is from the subject position. The agent-first strategy works; were grammatical capacity normal, it would yield the same solution—"girl" as agent.

Grodzinsky's theoretical analysis applies, as might be expected, to more than just cleft sentences. Generally, Broca's patients understand sentences in which constituents have been moved from subject position (for which the agent-first strategy works), and they show poor comprehension for sentences involving movement from object position (for which the agent-first strategy does not work). This generalization includes subject-relative sentences (good comprehension) and object-relative sentences (poor

comprehension)—two sentence types that will figure importantly in studies of real-time processing to be presented in a later section of this chapter.

13.2.4 Trace-Deletion-Hypothesis Updates

Syntactic theory is under vigorous development, and current work suggests that syntactic representations are richer in traces than previously thought—richer in traces than is suggested in government-binding theory, the theory informing Grodzinsky's trace deletion hypothesis. A recent development in this respect is that termed the verb phrase (VP)-internal-subject hypothesis (Kitagawa 1986; McNally 1992). The suggestion here is that the grammatical subject (even in simple active sentences) does not receive its thematic role directly from the verb. Rather the subject NP is claimed to originate within the VP and to occupy its surface position only by undergoing movement and leaving a trace behind. The assignment of a thematic role to the moved subject NP is, therefore, mediated by the trace. Only unmoved object NPs are directly assigned thematic roles.

Making use of the VP-internal-subject hypothesis, Mauner, Fromkin, and Cornell (1993) and Hickok (1992; also Hickok, Zurif, and Canseco-Gonzalez 1993) have independently reformulated Grodzinsky's trace deletion hypothesis. Both criticize Grodzinsky for his use of the agent-first strategy (they consider it an unnecessary theoretical encumbrance), and both offer the same alternative. For both, it is a matter of how many traces—or trace-antecedent chains—appear in any one sentence. If there is only one, all the Broca's patient need do is "fill-in" a thematic role by the process of elimination. But if there are two traces or chains, there are too many unknowns and the patient must guess.

This can all be illustrated by some examples provided in Hickok's (1992) analysis. The representations are for subject-cleft and object-cleft sentences—that is, for the same constructions considered earlier, but this time as specified by the VP-internal-subject hypothesis: respectively, "It was the girl; who [$_{VP}$ (f)$_i$ chased the boy]" and "It was the boy$_j$ [whom the girl$_i$ [$_{VP}$ *(t)$_j$* chased (f)$_i$]]." As in the earlier illustrations of the linguistic representations of subject- and object-cleft sentences, vacated positions are indexed by traces (f) and coindexation is shown by matching subscripts (either $_i$ or $_j$). What has been added to the representations here is that the VPs have been set out in brackets. This has been done in order to show the movement of the subject NP from within the VP. And, of course, it is this movement and its resultant trace that distinguish the present set of representations from those entered earlier when describing Grodzinsky's work. For the subject-cleft construction, the NP "the boy" is in object position of the verb "chased"; it has not undergone movement (this is the same as in Grodzinsky's analysis), and therefore it receives its thematic role—theme (the person being chased)—directly from the verb. Accordingly, the thematic role for the NP "the girl" (which has been moved from the subject position of "chased" within the VP) can be filled in. It can be assigned the role of agent, the one remaining role that fits in with a depiction of the sentence. By contrast, for the object-cleft sentence, both of the NPs have undergone movement. As in Grodzinsky's formulations, the NP "the boy" has been moved from its position as object of the verb "chased" (as indicated by subscript *i*); and, as now dictated by the VP-internal-subject hypothesis, the NP "the girl," this time being in subject position of the verb "chased," has also been moved (as indicated by subscript *j*). Both thematic role assignments must thus be mediated by traces. And since Broca's patients cannot capture antecedent-trace links for the purpose of comprehension, they cannot narrow their options—they cannot fill in. So they guess. In this manner, chance performance results from completely unspecified thematic assignment; unlike Grodzinsky's original formulation, there is no need to pit grammatical and nongrammatical (strategic) forces against each other.

The matter does not rest here, however. Grodzinsky (1993) has lately challenged the Mauner et al. and Hickok accounts. He bases his challenge on the demonstration that a different pattern of comprehension breakdown occurs for sentences featuring so-called "psych" verbs—verbs that do not take agents, but rather experiencers (as in, "It is the young man that Mary desires" where "Mary" is to be considered the experiencer of "desires," not its agent). In such sentences the nongrammatical strategic assignment of agent to the moved constituent "the young man" is not met by a like grammatical assignment of agent to "Mary"; rather, it is agent versus experiencer.

The consequences of this mismatch are taken up in the problems section. For the present, however, the similarity of these accounts must be emphasized, not their few differences. It should be apparent that Mauner, Fromkin, and Cornell, and Hickok, and Grodzinsky, before them, all agree on what is particularly problematic for Broca's patients; namely, the inability of these patients to represent intrasentence dependency relations involving traces and their resultant inability to understand noncanonical sentences in which constituents have been extracted from object position.

What is next considered is the source of this problem. The question here is whether the problem reflects a fundamental loss of syntactic competence or whether it reflects a processing disruption, according to which, knowledge of syntactic dependencies is still present but cannot be implemented during the act of comprehension. As forecast at the outset of this chapter, the evidence will suggest the processing explanation to be the more likely.

13.3 Processing Disruptions in Aphasic Comprehension

13.3.1 Dissociations between Comprehension and Grammatical Judgment

The idea that comprehension limitations of the sort described above are to be linked to processing disruptions turns on a discrepancy between judgment and comprehension data (Linebarger, Schwartz, and Saffran 1983)—not so much of a discrepancy as originally claimed (see Mauner, Fromkin, and Cornell 1993; Zurif and Grodzinsky 1983), but enough to be dramatic and surprising. Specifically, Linebarger, Schwartz and Saffran found that Broca's patients, with noticeable syntactic limitations in comprehension, were, nonetheless, able to detect a variety of grammatical deformations, including some that required an awareness of syntactic dependencies involving traces. So, for example, they could detect the ungrammatically of "Mary ate the bread that I baked a cake," where there is no empty position—no trace—to associate with "bread" (as there is in "Mary ate the bread, that I baked (*),").

What emerges from this is a picture of Broca's patients in which they can be seen to carry out quite complex judgments, yet lack the ability to exploit this sensitivity for comprehension. And this seems to call for a processing account—for recognition that the limitation is NOT due to some unalterable loss of knowledge that would be revealed on all tasks, judgment as well as comprehension. (See Shankweiler et al. 1989, and Wulfeck and Bates 1991, for different variations on this idea.)

The goal, then, is to specify the nature of the processing disruption: to determine where the defect is in the system that converts the input stream into an interpreted structure.

Linebarger, Schwartz, and Saffran (1983) suggest that the problem is one of thematic mapping, an operation that can be placed somewhere between syntax and meaning. In this view 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 (that is, agent, theme, and the like).

Upon reflection, however, the connection between grammatical judgment data and this mapping hypothesis seems to be very indirect and not particularly compelling. After all, the task of making a grammatical judgment about a sentence need not depend upon the normal construction of a syntactic representation. Consider again the example "Mary ate the bread that I baked a cake." As pointed out above, there is no trace after "baked" to associate with "bread." In effect, "baked" has too many arguments in this ungrammatical sentence. But noticing this need not require a fully elaborated syntactic analysis. Rather, all that need be done is to check the number of arguments that "bake" can take and the number of arguments locally present. And this is a very different matter from filling an empty position in a nondeformed sentence in real time—from establishing a dependency relation between a trace and its moved constituent during the strict time constraints imposed upon the initial structure-building process.

Moreover, even if it is a mapping problem, it is clearly not 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"; namely, that Broca's patients have noticeably more difficulty in mapping NPs that have moved and left traces than in mapping NPs that have not moved (Schwartz et al. 1987). But since this distinction is also at the heart of the various versions of the trace-deletion hypothesis (Grodzinsky 1986; Hickok 1992; Mauner et al. 1993), the "transparency" notion does not help us to decide whether the problem is one of mapping or of initially establishing the link between a trace and its antecedent. In order to make this decision, we must observe what happens as comprehension unfolds in real-time.

13.3.2 Priming and Gap-Filling

Techniques are now available with which to measure real-time operating characteristics of processes involved in syntactic analysis. The reference here is to the on-line techniques described by Fodor elsewhere in this volume; specifically, the priming techniques that enable us to detect the role of traces *during* sentence comprehension—that enable us to observe the real-time formation of a dependency relation between a trace and its antecedent.

Before discussing how these techniques have been applied to the study of aphasia, it will be helpful to review what priming is and how it has been used to examine normal syntactic processing.

Priming has to do with how lexical processing is facilitated under certain conditions. The measure used is either word naming time or lexical decision time—the time it takes to determine whether or not a string of letters forms a word. We will focus here on "semantic" priming, which refers to the finding that a lexical decision is faster for a target word when that word is immediately preceded by a meaningfully related word than when preceded by an unrelated word (Meyer, Schvaneveldt, and Ruddy 1975; Neely 1977). This result is taken to indicate that the first word—the prime word—has been present to aid the recognition of the subsequent, or target, word. And this, in turn, connects to the assumption of an automatic propagation of activation within a network of mental representations in which word meaning is enmeshed—a spread of activation from the mental representation of the prime word to representations of

semantically related words including the target (Collins and Loftus 1975; Neely 1977).

So, with respect to the detection of traces, if a target word related to the moved constituent is primed at the trace site (or gap)—that is, if at the gap, a lexical decision for such a target is faster than for a word unrelated to the moved constituent—if this happens, then it can reasonably be assumed that the moved constituent has been reactivated at the gap to provide the prime for the target. (See Fodor in this volume and Swinney and Fodor 1989 for reviews of this work.) This phenomenon is referred to as gap-filling. And such reactivation reliably occurs for certain forms of constituent movement as in cleft and relative sentences of the sort mentioned earlier. In effect, in these constructions, the trace appears to have a real-time processing consequence—one that can be defined in terms of a finely grained pattern of lexical reactivation.

13.3.3 Gap-Filling in Aphasia

The effects of focal brain damage on gap-filling are also now being examined. This work widens the perspective to include Wernicke's aphasic patients as well as Broca's. And it builds upon the rather consistent finding that Wernicke's patients, but not Broca's patients, show roughly normal lexical activation characteristics in circumstances that foster automatic processing—that is, in circumstances in which the processing is mandatory and not under the control of statistical bias or indeed any conscious strategy (e.g., Milberg and Blumstein 1981; Prather, Zurif, and Love 1992; Prather, Zurif, Stern, and Rosen 1992). In these circumstances Wemicke's patients, but not Broca's, show the normal pattern of facilitated word recognition (lexical decision) for targets preceded by semantically related primes.

Of course, the Wernicke's patients' data can be taken only to indicate initial lexical activation and the spread of this activation to semantically associated nodes. It does not necessarily signal a normally nuanced pattern of activation—a pattern by which only the correct node, the precise word meaning, remains active. Contrariwise, the Broca's patients' failure to show normal priming should not be taken to indicate complete insensitivity to prime-target relations. These patients are not, after all, disbarred from activating word meanings. Rather, on the evidence available, automatic priming in Broca's aphasia seems to be temporally protracted; or, more to the point, lexical meaning activation as revealed by priming seems to have a slower-than-normal time course (Prather, Zurif, and Love 1992; Prather, Zurif, Stem, and Rosen 1992).

The effects of the Broca's aberrant lexical activation might reasonably be supposed to ramify throughout the comprehension system. Gap-filling should be especially vulnerable. This is an operation that is implemented under strict time constraints. And, this being so, the inability of Broca's patients to represent antecedent-trace relations can be viewed in real-time terms as the inability to reactivate the moved lexical item at the normal time in the processing sequence—in time, that is, to fill the gap left by its movement.

It is this scenario that has lately been put to the test in two separate experiments (Zurif et al. 1993; Swinney et al. 1993).

The first experiment (Zurif et al. 1993) used subject-relative constructions of the sort, "The man liked the tailor, with the British accent who (f), claimed to know the queen." As shown by this example, movement from subject position is hypothesized. And in this respect the subject-relative construction is equivalent to the subject-cleft construction that has been used to illustrate both Grodzinsky's and Hickok's work. The shift from cleft to relative is motivated here only by the fact that normal gap-filling experiments have made greater use of the latter.

The subject-relative construction also offered the possibility of revealing whether the brain areas implicated in Broca's and Wemicke's aphasia are distinguishable in terms of the way in which each serves syntactic analysis. The relevant point in this respect is that Broca's and Wemicke's patients differ, not only with respect to lexical activation, 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 Wemicke's patients are unpredictable, more often than not showing chance comprehension (e.g., Grodzinsky 1984). So, do Broca's patients show normal syntactic analysis as suggested by Linebarger, Schwartz, and Saffran (1983)? Or does their aberrant lexical activation pattern disallow normal gap-filling, requiring, instead, a reliance on one or another non-grammatical strategy for thematic assignment? And, to consider a reverse situation, do Wernicke's patients show normal gap-filling even though they often ultimately fail to achieve a normal level of comprehension for this sentence type?

The assessment of gap-filling and the range of possibilities just outlined, turned on the use of the on-line task termed cross-modal lexical priming (CMLP) (Swinney, Onifer, Prather, and Hirshkowitz 1979; see also the Fodor chapter, this volume). The features of the task are these: Subjects listen to a sentence over earphones (delivered uninterruptedly and at a normal speaking rate) and at one point, while listening to the sentence, are required to make a lexical decision for a visually presented letter string—the target probe—flashed on a screen in front of them.

To discover whether the moved constituent was reactivated, or filled, at the gap (thus providing the prime), lexical decision times were recorded for antecedent-related target probes and for letter string probes that

formed semantically unrelated control words—that is, formed words that the antecedent could not prime. For the example given earlier, "The man liked the tailor,- with the British accent[1] who[2] (f), claimed to know the queen," the visual 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 the experimenters to distinguish structurally governed reactivation at the gap site from any residual activation due simply to the earlier appearance of the antecedent ("the tailor"). The inclusion of this pregap baseline was of particular importance when testing Broca's aphasic patients; in the face of their slower-than-normal lexical activation, residual priming was clearly a possibility. At any rate, at each point—pregap and gap—priming was determined by comparing the lexical decision time for the related visual probe to that for the unrelated visual probe.

The data that were obtained are straightforward. A control group of elderly, neurologically intact subjects and the Wernicke's patients showed gap-filling; the Broca's patients did not. Specifically, the neurologically intact and the Wernicke's aphasic subjects showed priming (relative facilitation in lexical decision for words related to antecedents) at gap sites but not at pregap sites. The Broca's patients did not show priming at either position.

The data clearly point to the different roles played by the brain areas implicated in Broca's and Wernicke's aphasia, respectively. The first-mentioned area is crucial for the real-time formation of intrasentence dependency relations—for gap-filling—in a way that the second is not. Indeed, the data show that the Broca's patients cannot normally establish such relations even for subject-relative sentences that they interpret at a level significantly above chance.

As earlier noted, a second experiment was also carried out (Swinney et al. 1993). In this one, object-relative sentences were used, these being equivalent to object-clefts in terms of constituent movement and trace location (just as subject-relatives are equivalent to subject-clefts). Actually, the object relatives were either plausibly or semantically constrained, since the intention was to have the patients actively listening for meaning. Even so, given the Broca's failure to fill gaps for subject-relatives, there was little expectation that they would normally form dependency relations for object-relatives. In fact, the interest in using object-relatives had mostly to do with Wernicke's patients. The aim was to broaden the base of observations of this group's gap-filling capacity, particularly because reactivation in subject-relatives might have been affected by the relativizer "who" in that construction and also because movement within subject-relatives has the special property of being "string vacuous"—such movement does not reorder any of the elements in the sequence.

Accordingly, the second study featured object-relatives of the sort, "The priest enjoyed the drink, that the caterer was[1] serving[2] (f), to the guests." Again, the CMLP task was used; and again, priming was assessed in two locations—at the gap indexed by the trace (superscript 2) and at a baseline, pregap position (superscript 1). At each location the experimenters recorded lexical decision times for visual probes related to the moved constituent and for visual probes forming unrelated control words. For the example given, "wine" was the probe for "drink" and "boat," the control probe. And once more, Wernicke's patients, like normal controls, filled the gap (and only the gap), whereas the Broca's patients did not. Again, regardless of ultimate sentence understanding, Wernicke's carried out the syntactic business of linking antecedents and traces, and Broca's could not.

13.4 Concluding Remarks

13.4.1 Wernicke's Aphasia and Functional Localization

The line of research that has been described here is clearly only just beginning. Experimenters have yet to determine, for example, whether Wernicke's patients reactivate only appropriate antecedents at gaps. Still, even now, experiments that have been done using two different sentence types point rather convincingly to the Wernicke's patient's sensitivity to structurally licensed gaps and to their ability to fill these gaps—to form dependency relations involving traces at either subject or object positions—as sentences unfold in real time.

What does this reactivation at the gap signify, however? Does it indicate that the Wernicke's patient is assigning a thematic role to the antecedent, whether agent or theme? Or does it reflect the consequences of an earlier processing stage—a stage at which the antecedent and trace are coindexed prior to such thematic assignment? In the light of work by Shapiro and his colleagues, the latter possibility seems more likely (Shapiro et al. 1993). These investigators have shown that Wernicke's patients are not normally sensitive during comprehension to the argument-taking properties of verbs. Unlike neurologically intact subjects, the patients are unable to access momentarily all the possible argument structure configurations within a verb's lexical entry—to access, for example, the information that a dative verb like "send" can allow both an agent-theme configuration ("He sent the book") and an agent-theme-goal configuration ("He sent the book to Mary"). In effect, the Wernicke's patients appear unable to generate thematic information in real-time in the normal manner. It seems reasonable, therefore, to view gap-filling for these patients as

being the reflection of processing that occurs at a stage prior to thematic assignment or mapping. The fact that they were capable of filling gaps in sentences for which they show uncertain comprehension strengthens this conclusion.

Whatever its precise role, however, it is clear that the brain region implicated in Wernicke's aphasia is not crucially involved in the reflexive syntactic activity of recognizing and filling gaps left by constituent movement as the sentence unfolds in real time.

13.4.2 Broca's Aphasia and Functional Localization

By contrast, the cortical region usually associated with Broca's aphasia does appear to be necessary for the operation of gap-filling. The data reviewed here show that Broca's patients are unable to form dependency relations involving traces—whether for object-relatives that they have difficulty understanding or even for subject-relatives that do not pose difficulty for them.

The consequences of this 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 information necessary for thematic assignment to moved constituents. Presumably, therefore, the Broca's patients rely abnormally on some nongrammatical strategy to achieve thematic mapping for moved constituents—on a fill-in strategy (Hickok 1992) or an agent-first strategy (Grodzinsky 1986). And when such strategies do not work, their comprehension fails.

Accordingly, the structural limitations in Broca's aphasia described by Grodzinsky; by Mauner, Fromkin, and Cornell; and by Hickok can be linked to disruptions of automatic lexical reactivation. Thus, the brain region implicated in Broca's aphasia need not be the locus of syntactic representations per se. Rather, in the view developed here, this region seems to provide the processing resources that sustain lexical (re) activation and its syntactic ramifications. Possibly, as already suggested, these resources sustain the normal *speed* of activation and reactivation. This would be in line with independent evidence of slowed lexical processing in Broca's aphasia (Prather, Zurif, and Love 1992), and it is a possibility that is currently being explored.

There are, however, other possibilities concerning the responsibility of the brain area implicated in Broca's aphasia. For example, several investigators have suggested that it accommodates the memory storage demands that arise during comprehension (Kolk and van Grunsven 1985). And, certainly, a prima facie case can be made that long-distance dependency relations of the sort described here are especially reliant upon some form of working memory capacity.

Another possibility is that the broad cortical area associated with Broca's aphasia sustains multiple functions, including both speed of input activation and working memory. And yet another possibility is that memory capacity is diminished only as a consequence of slower-than-normal lexical activation—only because of the increased cost of such activation.

The point that is common to all of these accounts, however—and indeed, the moral of this chapter—is that structural limitations statable in the abstract terms of linguistic theory can be traced to changes in cortically localizable processing resources. Thus, descriptions of language localization in the brain can be offered in terms of speed of activation and storage capacity—in terms, that is, of processes and processing resources that intuitively appear biologically fixed or "wired in." And this reduces the distance between cognitive science and neuroscience.

Suggestions for Further Reading

A detailed consideration of the trace-deletion hypothesis is to be found in Grodzinsky's book *Theoretical perspectives on language deficits* 1990. The updates of this hypothesis provided by Mauner, Fromkin, and Cornell and by Hickok figure as part of two special issues of the journal *Brain and Language* 45:3 (October 1993 and in press). All the papers in these issues, including several that provide cross-linguistic perspectives, are characterized by detailed linguistic analyses, a practice that is, unfortunately, not that common in aphasia research.

The processing issues treated here—gap-filling and the real-time access of argument structure configurations in aphasia—are also described in considerable detail in these issues of *Brain and Language.*

It ought to be apparent that the representational and processing matters covered in this chapter form only a very small part of aphasia research. For much wider coverage of current work—including studies of production, repetition, and other activities, marked by varying degrees of theoretical focus—see Goodglass's book *Understanding aphasia* 1993.

Problems

13.1 Although not mentioned in the text of this chapter, Broca's patients also have difficulty interpreting pronouns in sentences. Faced with "The boy kicked him," it is not uncommon for Broca's patients to take "him" to refer incorrectly to "the boy." As it happens, Hickok's (1992) version of the trace deletion hypothesis—framed within the VP-internal-subject hypothesis—tries to account for this difficulty. The question here is how Hickok's account works.

To answer this question, two additional notions must be entered. The first is in the form of a principle stating that a pronoun must be free (not corefer with a NP) in its governing category; and the second is the hypothesis that the relevant governing category is the VP (Kitagawa 1986). The answer can be formulated by applying these two notions to representations that show subject NP movement from inside the VP; that is, to representations that accommodate the VP-intemal-subject hypothesis. For the example given above, the representation is "The boy [$_{VP}$(f) kicked him]."

13.2 Grodzinsky (1990, 1993) has assessed Broca's patients' comprehension for sentences containing "psych" verbs. As noted in the text, verbs of this type replace the theta role of agent with that of experiences In "The man was hated by the woman," "the man"

is the theme and "the woman" can best be described as the experiencer of the emotion, not its agent. Granting this characterization, what finding would vindicate Grodzinsky's use of the agent-first strategy? Recall that this strategy figures crucially in his original trace-deletion hypothesis and that it has been abandoned in the Mauner Fromkin, and Cornell (1993) and Hickok (1992) revisions.

Question for Further Thought

13.1 The major point in this chapter is that representational limitations can be linked to rather elementary processing disruptions—in particular to alterations in the speed of lexical activation. To state the matter more generally, language localization in the brain appears to reflect, not a distribution of knowledge types, but the anatomical allocation of processing resources. But, if so, should these resources be considered linguistically specific or domain general? This question has yet to be answered.

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