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# The Neurological Organization of Lexical and Structural Operations in Sentence Comprehension: Findings and Methodological Considerations*

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## Introduction

Lexical processing plays a transparently necessary and central role in language comprehension. In what follows, we discuss the connections between lexical activation and lexical integration in the construction of interpreted syntactic representations during sentence comprehension. We provide a basis for inferring how different brain regions support this connection, and we discuss some methodological issues relevant to this type of investigation. Throughout, our concern is with the distinction between rapid-acting, time-constrained processes and relatively temporally unconstrained processes that, together, constitute language comprehension.

Our starting point here is one that Prather, this volume, covers in far greater detail and depth. We repeat just the critical points to support our later observations. These points center on the consistently reported observation that Wernicke's aphasic patients, but not Broca's aphasic patients, demonstrate roughly normal automatic lexical access functions (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 general observation stems primarily from studies of lexical priming, which is the facilitation found for the processing of a word in the presence of a semantically or associatively related word (see, e.g., Meyer, Schvaneveldt & Ruddy 1975; Neely 1977). Thus, Wernicke's but not Broca's aphasic patients demonstrate the normal pattern of facilitation from semantically and associatively related contexts on, for example, a lexical decision made to a letter string.

This said, we note that Wernicke's patients are not entirely normal in their access of word meaning. While existing data suggest normal initial contact with lexical representations takes place for Wernicke's patients, they do not rule out the possibility of something like a "coarse-coding" - a less-than-precise apprehension of a word's mean-

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the lesion sites that underlie Broca's aphasia are distinguishable from those that underlie Wernicke's aphasia). [1]

## Studies of gap-filling with Broca's and Wernicke' aphasic patients

As just mentioned, dependency relationships have processing consequences for the processing in 'neurologically unimpaired' populations. As establishing such relationships is done on-line, immediately at the site of `extraction' form movement, it is clear that this is an operation that is implemented under strict time constraints and one that is unlikely to accommodate slower-than-normal lexical activation. This being so, it seemed to us reasonable to hypothesize a connection between the Broca's aphasics' slowed lexical processing and their syntactic limitation. Specifically, we hypothesized that the Broca's inability to interpret antecedent-trace relations might be a failure to reactive or integrate `moved' constituents at the normal time in the processing sequence - in time, that is, to fill gaps in the structural relationship left by their displacement.

We have examined this hypothesis by assessing the time-course of reactivation of antecedents to moved positions (known as 'gap-filling' in psycholinguistic parlance) in Broca's patients and Wernicke's patients in two experiments (Zurif, Swinney, Prather, Solomon & Bushell 1993; Swinney, Zurif, Prather & Love 1993, respectively). In the first of these we used subject-relative constructions such as:

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

As shown by this example, movement from subject position is hypothesized in many linguistic characterizations. (We use the (t), following standard linguistic notation, to indicate a `trace' in the position from which the element (tailor) was hypothesized to have `moved'. We chose this construction because of the perspective it offered both within and across aphasic groups. Broca's patients show relatively normal comprehension for this construction, but Wernicke's patients are unpredictable, more often than not showing chance comprehension (e.g., Grodzinsky 1984; Shankweiler, personal communication, February 1992). So for Broca's patients these sentences provided the strongest test of our suggestion that they could not carry out normal syntactic (co-reference, dependency) analysis in real time. This would allow us to determine if slower-than-normal lexical activation disallowed normal 'gap-filling' even for sentences correctly comprehended and, further, would also allow us to determine if, in such circumstances, Broca's patients were abnormally reliant on non-grammatical strategies. With regard to the Wernicke's patients, this construction allowed us to determine whether the reverse scenario held: that, even though they would often ultimately fail to understand these sentences, their initial access to (and information rise time from) lexical entries would be normal and hence they would demonstrate a `structural reflex' and appropriately `fill' the gap by reactivating the appropriate antecedent at the appropriate time during processing.

Our assessment of gap-filling and the range of possibilities just outlined, employed the cross-modal lexical priming (CMLP) paradigm (Swinney, Onifer, Prather & Hirshkowitz 1979). In this, 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 (word/nonword) decision for a visually presented letter string flashed on a screen in front of them. (To accommodate the right-sided weakness of Broca's patients, all subjects "button-pressed" with their left hand when making their decisions.) We sought to discover whether a letter-string probe forming a word related to the moved constituent (the antecedent) was primed at the site of the `gap' (indicated by the (t) in the sample sentence). Such priming would indicate that the moved constituent was reactivated at the gap (thus providing the prime for the lexical decision).

For each of our experimental sentences, we recorded lexical decision times either for antecedent-related probes or for letter string probes that were semantically unassociated control words. For the example given above, the probes were "clothes" (the probe for the antecedent, "tailor") and "weight" (the control probe).

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

One of the key reasons for our use of the CMLP task to study on-line processing is that the lexical decision, itself, does not require that the subject consciously seek a relation between the visual probe and anything in the orally presented sentence (as is the case, for example, in experiments utilizing a probe-latency task or an off-line technique). Rather, at least until the visual letter string is presented, the subject is simply listening and trying to understand the sentence. (Subjects are further encouraged by the random presentation of comprehension questions between trials.) Once the visual probe is presented all such normalcy ends, of course. But this happens only after the point of theoretical interest concerning sentence processing has passed.

Our findings for this experiments are presented in Table 1. As can be seen, the Wernicke's patients reliably filled gaps (as did our neurologically intact subjects who were used to pretest the sentences). This can be seen by evidence of significant priming for the related (as contrasted with the control) `probe' at the `gap' site; the `reactivated' antecedent acted to prime the lexical decision to the related word presented at that point in the sentence. The Broca's patients did not show any evidence that would lead us to believe that they filled the gap at this point in processing. (There was no significant priming to the related antecedent.) Our initial interpretation, then, is that it appears that the brain areas respectively implicated in Broca's and Wernicke's aphasia have different functional commitments - the former appears to be crucial for the real-time construction of intra-sentence dependency relations in a way that the latter is not.

Our second study on this topic employed object-relative sentences. Given the Broca's patients' failure to fill gaps for subject-relatives (sentences that they understand), we

**Table 1** Amount of Priming (Reaction Time to Control Probes Minus Reaction Time to Related Probes) in milliseconds for subject-relative constructions

| POSITION | baseline (pregap) | gap |
|---|---|---|
| WERNICKE'S PATIENTS | 44 | 125* |
| BROCA'S PATIENTS | -20 | -68 |

* Significant priming ($p < .03$)

had little expectation that they would show gap-filling for object-relatives (sentences that they fail to interpret). However, our interest in using object-relatives had to do mostly with Wernicke's patients (who also show less-than-normal comprehension for such sentences). We wanted to broaden the base of our 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" (e.g., Clements, McCloskey, Maling & Zaenen 1983) in that such movement does not reorder any of the elements of the sequence. We felt re-ordering was a critical aspect of the `movement-from-canonical-position' aspect of dependency relations that we were interested in, and thus, this second study featured object-relative sentences of the type:

"The priest enjoyed the drinki that the caterer was $^{*1}$ serving (t)i $^{*2}$ to the guests."

We used the CMLP task, and again, we checked for priming both at the gap (superscript $^{*2}$ and at a baseline, pre-gap position (superscript $^{*1}$). For the example given, "wine" was the probe for "drink" and "boat", the control probe.

As can be seen from Table 2, the Broca's patients again did not show significant priming at either probe site. (They did, however show some (nonsignificant) advantage for related probes (relative to control probes) at the baseline position. In effect, for this group there was no sign of structurally determined reactivation of the antecedent, only a sign of some residual activation - the consequence, likely, of having processed the earlier appearance of the constituent in a slowed-down fashion. As for the Wernicke's patients, they once more showed priming at the gap and only at the gap, and again, this pattern corresponded to that shown by the neurologically intact subjects with whom we pretested the material.

A number of conclusions may be drawn from the data of these two studies. The first is that cerebral tissue implicated in Wernicke's aphasia is not crucial for the establishment of intrasentence dependency relations. However compromised their understanding of language is, the problem does not turn on a failure of the sort of structure building charted here.

By contrast, the brain region implicated by Broca's aphasia does appear to be necessary for this operation of syntactically governed reactivation. Our data show that Broca's aphasic do not construct syntactic representations normally in real time.

**Table** 2 Amount of priming (Reaction Time to Control Probes Minus Reaction Time to Related Probes) in milliseconds for object-relative constructions

| POSITION | baseline (pregap) | gap |
|---|---|---|
| WERNICKE'S PATIENTS | 3 | 108* |
| BROCA'S PATIENTS | 122 | -9 |

* Significant priming ($p < .02$)

Presumably, therefore, they must rely on other processes to achieve the level of comprehension they show in conversational settings. Such processes may involve semantic and/or pragmatic cues, and, indeed, the experimental sentences used in this study provided such cues. (Where such cues are not present Broca's show rather poor comprehension (see, e.g., Ansell & Flowers 1982; Caplan & Futter 1986). We hypothesize that, in fact, these cues, when presented to a temporally-less demanding level of analysis (as one might find, for example, at discourse-level processing) may well allow comprehension to proceed even in the face of temporally constrained, structure building failures such as we have charted here for this population. Wernicke's patients also have problems with such sentences when they are semantically and pragmatically unconstrained. But, as we show here, these ultimate failures turn on disruptions at different points in the processing chain, not at that involving temporally demanding information integration.

We suggest here that the disruption shown by Broca's can be rooted to general slowing of availability of information typically derived from lexical activation and integration. What we have shown here is the way in which this problem ramifies to the syntactic level. In this view, 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 (automatic) operating characteristics of the lexical and structural processing systems (namely, rapid-temporal-processing). That is, we suggest 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 rapid temporal integration of language information, as seen in lexical access and structural integration.

## Some Final Methodological Issues

The work we have presented here carries with it certain methodological assumptions. Claims about the nature of language processing must be investigated in the framework of paradigms that examine sentence or discourse processing, and not just the processing relations that hold between isolated words. While isolated (or pair or triplet) word studies do, indeed, reflect something of how relations between words can

be exploited, the extra-sentence-processing characteristics they bring divorces such findings from valid interpretation with regard to sentence-discourse processing. This is not to say that only work in sentence contexts can reveal important language processing characteristics. Indeed, the issue is one of whether the non-sentential task allows for extra-sentential strategies to affect processing of the material. Thus, while continuous lexical decision tasks prevent pair-wise strategies from developing, paired-presentation of words, obviously, does not.

Next, it needs to be pointed out that, while on-line studies are critical to the investigation of sentence/discourse comprehension, not everything that involves reaction time or speeded response is a valid on-line measure of such processing. Thus, for example, speed to detect grammatical deformations likely bears little relationship to what goes on in language comprehension. Further, most off-line techniques are simply not capable in principle (and fact) of distinguishing the types of moment-by-moment details that are needed to build models of ongoing processing. By off-line measurements we refer to those that merely study (or ask evaluation of the final `percepts' of language processing - as in sentence enactment, sentence-picture matching, truth-value judgment grammaticality or acceptability judgment tasks. Their worth in helping us think about representational limitations is indisputable. But they have not been particularly valuable in helping us explain these limitations in processing terms.

Linebarger, Schwartz & Saffran's (1983) interpretation of their grammaticality-judgment data can be used to illustrate this last point. Their finding is that Broca's patients carry out quite complex syntactic judgments, showing in this respect a sensitivity to structure and to grammatical categories (e.g., empty categories) that they are unable to exploit for comprehension. Linebarger et al. (1983) take this to indicate that the Broca's comprehension problem is not at the level of syntactic processing, but at a later processing stage - at the stage of thematic role assignment or mapping. However, these off-line grammatical judgment data do not at all militate this interpretation. It is one thing to notice the absence of an empty (trace) position in a deformed sentence; quite another, to link the trace with its antecedent in real-time - to fill the gap indexed by the trace during the strict time constraints imposed on the structure-building process. As simply one of many possibilities, it is entirely possible that performance in the first (off-line) instance is based on a local "checking" procedure - a post-sentence problem solving process in which locally available antecedents are checked against any open (unfilled) verb arguments. This kind of top-down, strategic intervention is likely to be far removed from gap-filling - from the normal reactivation of an antecedent at its post-verb cannonical position in real time (e.g., Swinney & Fodor 1989). Thus, although the off-line judgments charted by Linebarger et al. (1983) indicate the Broca's patient's sensitivity to empty categories, the data do not help us fill in details from a real-time processing perspective. In particular, they do not help us distinguish processing at the syntactic level from processing at a later stage. To isolate such stages we need to apply on-line techniques - techniques that can be brought to bear on ongoing processes at any temporal point in processing of a sentence, and which add as few extra-language processing characteristics (demand characteristics) of their own as possible. It is only with such tasks that we will be able to further a detailed analysis of the functional commitment of brain resources to language processing.

## Note

1 While there is considerable variation in lesion extent, particularly for Broca's aphasia which is associated with large superficial and deep lesions, including the posterior portion of the third frontal gyrus, the anterior insula and adjacent and deeper areas, the fact is that the modal lesion site for this form of aphasia is different from that for Wernicke's aphasia, where the greatest involvement is inferior to the Sylvian fissure, implicating especially areas located in the posterior superior portion of the first temporal gyrus (Benson 1985; Vignolo 1988; Mohr 1976).

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