Chapter 3
Neuroanatomical organization of sentential processing operations: Evidence from aphasia on the (modular) processing' of discontinuous dependencies

DAVID SWINNEY, TRACY LOVE, JANET NICOL, VIKKI BOUCK AND LEA ANN HALD

Introduction

Our current understanding of the neuroanatomical organization of human language processing has been derived nearly in its entirety from observation and studies of language disorder arising from brain damage - from studies of aphasia. However, due to the ever-evolving behavioural description of language itself, our evolving understanding of the attendant cognitive processing resources underlying language, and our increasingly detailed knowledge of brain architecture, a 'final' description of the neuroanatomical organization of language is far from within our grasp. This chapter attempts to move toward a more complete description of language representation in the brain by focusing on processing at the level of description where language structure, processing resources and brain architecture are all most apparent - the level of sentence comprehension. In this chapter, we examine a specific (and demonstrably modular) process in comprehension - the processing of discontinuous dependencies - in normal and aphasic adults, and we detail the nature and time-course of this processing system as revealed by patterns of mental activation in these populations. Ultimately, we link a failure in the processing of these dependency relationships in certain brain-damaged populations to a neurologically localizable and elemental processing disruption, therein providing a basis for inferring how different brain regions subserve aspects of language comprehension. We will first discuss

the types of intra-sentential relationships that will be the focus of this chapter, followed by a consideration of methodological issues that are central in any attempt to examine 'natural' language processing. Then we will present processing evidence from non-brain-damaged populations in dealing with these sentence-level relationships, and conclude with presentation of evidence from aphasia about the processing (or lack of processing) of these same relationships.

Background issues: the nature of dependency relationships

Language is rife with a variety of types of dependency relationships which are generally termed 'discontinuous' or 'long-distance'. We will deal with two classes of these in this chapter. The first, co-referential relationships, are concerned with relationships such as that which holds between a pronoun and its antecedent, as in the sentence:

1. The baker told the waitress at the restaurant that he would be late for work.

Here, the pronoun 'he' refers to the antecedent 'baker'. The question for the processor, of course, is how and when during processing the link between two dependent elements which are some distance apart (here, 'he' and 'baker') is accomplished.

The second type of long-distance dependency relationship which will concern us is structurally based - i.e. based on the fact that elements which are believed to be directly linked (and represented contiguously) in the 'underlying' or canonical representation of a language can be separated in surface forms of the language. For example, consider the object-relative construction in English:

2. The baker talked to the waitress who the customer accused of rude behaviour.

Two underlying sentences (propositions) comprise this complex sentence:

2a. The baker talked to the waitress.
2b. The customer accused the waitress of rude behaviour.

Note that in each 'underlying' sentence there is a canonical Subject-Verb-Object word order (this holds particularly for English, which is a strong S-V-O word-order language, and is more debatable for languages that allow various orderings of subjects, verbs and objects in declarative sentences). Thus, in the surface form of this complex sentence, the object

antecedent NP to which they refer (see e.g. Corbett and Chang, 1983; Bever and McElree, 1988; Tanenhaus, Carlson and Seidenberg, 1985; Tanenhaus, Stowe and Carlson, 1985; see, however, Caramazza, Grober, Garvey and Yates, 1977). Although these studies demonstrated this apparent `fact' via somewhat different methodologies, a number of the more influential of these investigations employed an end-of-the-sentence probe verification task in their work (the exception to this is Tanenhaus, Stowe and Carlson, 1985 who used a word-by-word reading task). One problem in interpreting these end-of-sentence probe studies is that the measures they use are taken temporally *after* the event of interest, thus confounding the results with `off-line' factors such as conscious rumination, etc. Further, the time at which `linkage' takes place during processing of the sentence obviously cannot be readily specified with this task. For this reason (and the others stated above) much of the more recent behavioural work in this field has involved the use of `on-line' tasks such as CMLP

Nicol (1988), for example, utilized CMLP to examine the reactivation of antecedents to both pronouns and reflexives during ongoing processing, employing sentences such as:

5. The swimmer told the skier that the doctor for the team was sure to blame *him* for the accident.
6. The swimmer told the skier that the doctor for the team was sure to blame *himself* for the accident.

Nicol (1988) found that for sentences such as (5), both `swimmer' and `skier' (all of the structurally permissible antecedents) were activated (primed relative to their controls) *immediately* after the pronoun occurred, whereas only the structurally correct antecedent, `doctor' was reactivated after the reflexive in sentences such as (6). Thus, by utilizing these essentially identical sentences which differ only in terms of the pro-form employed (which makes them subject to different structural constraints governing reference), Nicol determined that: (1) only *syntactically legal antecedents* are reactivated (linked) to pro-forms during ongoing comprehension and that (2) this linkage occurs *immediately* upon encountering the pro-form in the sentence. This evidence, then, substantiates inferences from the earlier off-line work, and provides an initial indication of how certain discontinuous dependencies are processed `on-line'.

The processing of structural dependencies by non-brain-damaged adults

A series of studies utilizing the CMLP technique (begun in 1982) have examined the linkage of the `moved' direct object in object-relative constructions to its canonical position (following the verb) in sentences.

The first of these studies was undertaken in 1982 by Ford, Frauenfelder, Bresnan and Swinney and first reported in Swinney, Ford, Frauenfelder and Bresnan, 1987 (and referred to again in Nicol and Swinney, 1989). This study examined the processing of object-relative constructions such as in sentence (3) above (and repeated here):

> The policeman saw the boy who the crowd at the party *[1] accused *[2] of the crime

At each test point, activation for the three first nouns in the sentence was examined at points both before and after the verb (at the baseline and gap positions, respectively). Thus, for this example, words related to: `policeman', `boy' and `crowd' were presented at each of the two test points (as were unrelated control words) in a completely counterbalanced design. The results are easily described: at test point * 1 (the `baseline' position) there was significant priming found for visual target words related to the last noun (e.g. `crowd'), but there was no significant priming for words related to either the first noun (e.g. `policeman') or the second noun (e.g. `boy'). However, at test point *2 (at the point of the gap - the structural dependency) there was significant priming *only* for the visual target related to `boy' (the correct filler) but not for targets related to either `policeman' or `crowd'. Finally, there was a significant interaction between the factors of test point (*[1] vs. *[2]) and target type (related vs. control - priming) for the word `boy' (see Table 3.1 for details).

Table 3.1. Priming scores in ms (lexical decision reaction times to control minus semantically related word) for each potential referent, at each probe point

	Probe point	
Referent	1	2
Boy	12,,,	27*
Crowd	44*	19,,,

* indicates significance at $p < 0.05$ in tests of *a priori* planned paired-comparisons (t-tests).

Several conclusions follow from this initial study. First, reactivation of the appropriate antecedent for a structural gap occurs *immediately* - as soon as it is discovered there is no direct object following the verb. This result is in keeping with results from other methodological techniques such as reading times at potential gap sites (e.g. Crain and Fodor, 1985; Stowe, 1986) and Evoked Potential measures (e.g. Garnsey, Tanenhaus and Chapman, 1989) which also support the conclusion that once a verb which requires a direct object is encountered (and no direct object is found), a search for a prior-occurring direct object is undertaken immedi-

ately, resulting in reactivation of that NP Further, these results suggest that the search for the direct object is not performed at random or in a way that reactivates all previous NPs; rather, *only* the actual (correct) filler is reactivated. Thus, the link between a verb and its displaced direct object is guided by structural knowledge. For example, such knowledge dictates that the missing direct object can *not* be the subject of the verb for which it is also a direct object (e.g. the word, `crowd'; no priming was found for the target related to `crowd' at the test point following the verb). Note that there was no priming for a target related to the appropriate antecedent filler for the gap ('boy') at the test point prior to the gap (the baseline). Thus, it appears that the process which establishes a link between a gap and its antecedent/direct object is *verb-driven* (in that the direct object is not activated and then kept active until a verb is found, but, rather, it is reactivated after the verb is understood). In short, this early study strongly suggested that the connection between a filler and a structural gap was an immediate, structurally driven, automatic process in comprehension.

A number of subsequent studies utilizing the CMLP technique have been performed which provide more detail about the nature of this process. For example, Love and Swinney, 1996, examined a large number of temporally distributed test points during comprehension to obtain more detail about the time course of reactivation of such direct-object antecedents during comprehension. They also examined whether the search for antecedents was conducted over a surface structure form of the sentence, or over a `deeper' sentential representation. To do this, they utilized lexical ambiguities as direct objects in object-relative constructions. The reasoning behind this study is based on the well-established findings that all meanings of a lexically ambiguous word are initially activated when the word is heard (e.g. Swinney, 1979; Tanenhaus, Leiman and Seidenberg, 1979). Thus, if all meanings of the ambiguous direct object (filler) are found to be reactivated at the gap position following the verb, an argument could be sustained that the search for an antecedent filler occurs over a surface (acoustic) representation of the sentence. However, if only the `contextually appropriate meaning' of the antecedent direct-object ambiguity is reactivated after the verb, then the search for the antecedent must be over a `deeper' representation of the sentence - one in which a single meaning for the ambiguous word has been determined and stored.' Subjects were presented (auditorily) with sentences such as:

7. The professor insisted that the exam be completed in ink, so Jimmy used the new *pen**[1] that his mother-in-law recently*[2] purchased*[3] – because the multiple colours allowed for more creativity.

Priming for each meaning of the filler `pen' (i.e. `pencil' and `jail') was examined at each of three target presentation points (marked by *). Significant priming for both meanings of the ambiguity (the primary, most

frequent meaning - `pencil' and the secondary, less frequent meaning- Jail') occured at test point #1 - immediately following initial occurrence of the ambiguity in the sentence. (This provided yet another demonstration of exhaustive access of word meanings for lexical ambiguities in biasing contexts).[5] At test point #2 (prior to the critical verb, but after the initial occurrence of the antecedent direct object), no significant priming was found for either the primary or secondary meaning of the ambiguity., Finally, at the critical test point #3 (immediately following the verb), a significant priming effect was found for just the primary (and contextually relevant) meaning of the ambiguity; there was no significant priming for the secondary meaning of the antecedent direct object. The interaction between the non-significant effect at test point #2 and the significant effect for the primary meaning of the direct object at test point #3 was itself significant, indicating that only the primary meaning of the ambiguity was, significantly reactivated at the gap.

This study found reactivation rather than continued activation for the filler, and hence supported the verb-driven account that what triggers reactivation of the filler is the failure to find an object after a verb which requires an object. Furthermore, this study demonstrated that the search for the direct object takes place via a deep, non-surface, representation of the sentence (because only one meaning of the ambiguity was reactivated, rather than all meanings).

In a related study, the effect of plausibility in `guiding' this linkage of the verb and direct object in object-relative constructions has been initially examined, with a goal of examining issues concerning the modularity of this process (i.e. the independence of this structurally driven process from world knowledge). In this study, subjects heard sentences such as:

8a. Everyone watched the enormous heavyweight boxer that the small 12-year-old boy on the corner had*' hugged*' so intensely.
8b. Everyone watched the enormous heavyweight boxer that the small 12-year-old boy on the corner had*' beaten*' so brutally.

The NP `the enormous heavyweight boxer' is a plausible direct object of the verb `hugged' in 8a but it is *not* a plausible direct object for the verb `beaten' in 8b. It is, however, the structurally correct antecedent filler (object) in both cases. In both sentence types significant priming was obtained for target probes related to `boxer', but not for those related to `boy' immediately after the verb. Thus, these results support the view that the linkage between the verb and displaced direct object, although structurally driven, is independent from top-down knowledge/plausibility information. Hence the process is putatively a modular one.

Finally, from recent work (Swinney and Love, 1998) we know that the rate of processing (the speed at which the speech arrives to the listener) considerably changes the parameters of this reactivation process - thus

implicating factors of memory and automaticity in the recovery of structurally based discontinuous dependencies.

Thus, we know that the processing of discontinuous dependency relationships is driven by a need to recover an underlying, canonical order of perceptual/sentential elements during ongoing comprehension. The process is triggered by the discovery of an `incomplete' structural relationship in the surface form of the sentence - i.e. a verb which requires a direct object, where no direct object is found following the verb. The process by which the verb is linked to the direct object involves the search of a non-superficial, meaning-based representation of the sentence. That search is initiated immediately (not at the end of the sentence, but immediately once the direct object is detected as missing), and it is structurally driven. Finally, the search is neither changed nor directed by semantic/world knowledge/plausibility, but it is considerably affected by rate-of-speech.

The processing of overt anaphors (pro-forms) in brain-damaged adults

The remainder of this chapter will focus on what information can be gained by exploring the on-line processing of people who have sustained unilateral damage to localized areas of the brain. These brain damage populations serve as a unique resource to examine the neural architecture of the brain with respect to language function.

It is widely accepted that differential damage to particular areas of the left hemisphere (and typically not the right) causes language impairments (aphasia) in most right-handers. (However, there has been much debate about the issue of the localizability of language within the left hemisphere, and about whether or not the right hemisphere has any language capacity at all.)

The results from off-line unconstrained assessment of language and classic standardized testing measures (e.g. Boston Diagnostic Aphasia Examination, Goodglass and Kaplan, 1972b) have discriminated a number of major groups of language impairment within the brain-damaged population. Two groups in particular have been of special interest: those who appeared to have overt production deficits with relatively spared comprehension (Broca's aphasic patients) and those who displayed the opposite patterns of behavioural deficits - fluent speech production with impaired comprehension (Wernicke's aphasic patients). [6] It was discovered that these distinctions did not actually hold when a careful investigation of the language abilities was performed (Caramazza and Zurif, 1976). In fact, via sentence-picture matching tests, it was discovered that those patients classified as Broca's aphasic patients displayed distinct comprehension problems in addition to their production deficits.

In investigating the role(s) of particular neural regions in real-time language comprehension, a number of studies employing the cross-modal

priming paradigm have been conducted. The studies described below investigate the processing of both antecedent-pronoun and filler-gap dependencies.

Work that is currently in progress looking at the processing of overt pronouns and reflexives during sentence processing strongly suggests, at least with respect to language processing, that there are differential roles of the neural substrates underlying the two aphasias. In this CMLP study, three Broca's, three Wernicke's, and two right hemisphere damaged control patients were presented with sentences that contained either a pronoun or reflexive (modified from Nicol, 1988) such as (9).

9. The boxer; said that the skier; in the hospital had blamed *himJself* for the recent injury.

In addition, they were presented with visual probe words which either were semantically related to the second NP *(skier* in example above) or were unrelated control words.' The results for the Wernicke's aphasics and unilateral right hemisphere damaged (control) patients are very straightforward: at the offset of the reflexive *(himself)* there is significant facilitation for words related to *skier* (the structurally-appropriate antecedent), but at the offset of the pronoun, there was no such facilitation for words related to *skier.* (Right hemisphere patients: 92 ms priming effect for the reflexive condition and 11 ms effect for the pronoun *condition;* Wernicke's aphasic patients: a significant priming effect of 44 ms for the reflexive condition and a non-significant priming effect of 10 ms for the *pronoun* condition.) The Broca's aphasic patients, on the other hand, demonstrate a very different (aberrant) pattern of effects: *significant* facilitation for words related to *skier,* after processing the *pronoun* (69 ms priming effect) and a non-significant effect of 9 ms for the *reflexive condition.* Here the normal structurally guided co-referential reflex is clearly disrupted, suggesting that the neural region typically involved in Broca's aphasia plays a critical role in the automatic routines underlying coreference during auditory sentence comprehension.

This dissociation in processing extends to other types of constructions as well. In investigating subject relative clause *constructions,* Zurif, Swinney, Prather, Solomon and Bushell (1993) presented sentences such as `The man liked the tailor; with the British accent *1 who, *7 claimed to know the queen'. In this sentence, there is a co-referential link between *the tailor* and the relative *pronoun who* .[8] As seen in Table 3.2, results from this study with Broca's and Wernicke's aphasic patients revealed a striking dissociation: Wernicke's aphasic patients displayed `normal' processing (reactivation of antecedent at the point of the relative pronoun) with no evidence of activation at the baseline position, and Broca's aphasic patients displayed an aberrant pattern of processing at the point of the pronoun (no priming for the correct antecedent).

Table 3.2. Priming effects (in ms control minus experimental) for subject relative constructions for both Broca's and Wernicke's aphasic patients at both the baseline (prior to relative pronoun) and `gap' (following the relative pronoun) position.

	Baseline (*1)	Following relative pronoun (*2)
Wernicke's	+44	+125*
Broca's	- 20	- 68

* $p < 0.03$.

The processing of discontinuous structural dependencies in brain-damaged adults

Swinney, Zurif, Prather and Love (1996) found the same pattern of results obtained with these populations for object-relative clauses as they did for the pro-form and subject relative cases just described above. They presented Broca's and Wernicke's aphasic patients with sentences such as `The priest enjoyed the drink. that the caterer was *[1] serving t, *[2] to the guests.' Again, using the CMLP paradigm, they found evidence for reactivation of the antecedent at the gap (*Z) for Wernicke's aphasic patients but not for Broca's aphasic patients [again, with no priming at a baseline position (*'), hence reactivation occurred] (see Table 3.3).

Table 3.3. Priming effects (in ms) for control minus experimental relative constructions for both Broca's and Wernicke's aphasic populations at both baseline (pre-verb) and gap (post-verb) positions

	Baseline (control minus experimental)	Following verb (control minus experimental)
Wernicke's	+3	+ 108*
Broca's	+122	-9

*$p < 0.02$.

Taken together, these findings suggest that the area of the brain affected by Broca's aphasia is crucial for the automatic reflexes responsible for rapidly establishing links among sentence elements consistent with the time constraints on sentence processing. In contrast, the Wernicke's aphasics showed no impairment in the automatic processes involved in such computations. However, they do typically show robust impairments in overall comprehension. Therefore, the region implicated in Wernicke's area may be involved in later-acting processes, such as integration of whole-sentence information or the computation of sentence-level meaning.

Acknowledgements

The authors gratefully acknowledge support from NIH DC02984, NIH D000494 and NIDCD DC01409 for the research reported in this chapter and the National Center for Neurogenic Communication Disorders at the University of Arizona for supporting the writing of this chapter.

Notes

` This concept comes principally from formal linguistic theories in which underlying thematic/semantic relationships (meaning) are treated as a constant that is maintained regardless of the superficial form of the sentence (transformational and related linguistic approaches); hence the distinction between deep and surface structure in Generative Transformation Grammar, Chomsky (1965); see also Government and Binding Theory, Chomsky (1981).

2. Note that all effects are evaluated in comparison to lexical decision reaction time to a `control letter string' presented at each of these test points; a `control letter string' is a word that is associatively/semantically unrelated to the key word in the sentence, but which is matched to the `experimental' (related) letter string on the basis of *a priori* reaction time (lexical decisions taken on the words presented in isolation).

3. McKoon and Ratcliff,1994 (see also McKoon, Ratcliff and Albritton, 1996) have presented arguments in which they have suggested that use of the CMLP technique for examining structural processing contains a confound - namely that the `visual experimental target words constitute better `continuation' (or, a better `fit with') the ongoing sentence than do the `control' target words. Thus, they claim that priming found in these studies is an effect caused by the 'goodness-of-fit' of probes into the sentence, and not by 'reactivation' or `continued activation' of the filler. For the record, the single example McKoon and Ratcliff discuss *did* have such a confound. However, in all other studies (including those presented here) the experimental and control probes have been equated for all types of 'goodness-of-fit' at each probe point, and hence *no* such confound exists for any of these results, thus invalidating McKoon and Ratcliffs claims. In short, the CMLP task is a sensitive and unconfounded measure of lexical activations during structural processing. See Swinney, Nicol, Love and Hald (1998), as well as Nicol, Swinney, Love and Hald (1997) and Walenski (1997), for further discussion of this and related issues.

`This study also controlled precisely for various potential confounds in the original CMLP study on this phenomenon; see e.g. McKoon and Ratcliff (1994) and Nicol, Fodor and Swinney (1994).

5. We note in passing that strong biasing contexts which exactly replicated the Tabossi (1988) criteria were employed in this study, but they had no effect on lexical access - again strongly supporting the claim of initial contextual independence for lexical access.

6. The aphasia classifications are named after the neurologists who discovered the neuroanatomical link to the particular behavioral deficit (Broca in 1861 and Wernicke in 1874). Broca's area is located in the third frontal convolution of the left hemisphere (Brodmann 44). Wernicke's area is located in the posterior regions of the left hemisphere, superior temporal gyrus (Brodmann 22).

'- Based on the existing evidence in the literature for an automatic linking of the antecedent and the co-referent (Nicol, 1988; Fodor, 1989 to name two), this study was simplified so as to only test for one of the noun phrases - in particular, the second

noun phrase (the correct antecedent for the reflexive). Moreover, again for design simplicity, only the offset of the overt anaphor was tested.

[8] We note here that although this is a case of co-reference involving *a relativepronoun,* it is also a potential case of a structural dependency - created by the putative movement of the subject from the position now occupied by the relative pronoun. Hence it bridges the co-reference and structural-dependency cases.