Context Effects in Syntactic Ambiguity Resolution: The Location of Prepositional Phrase Attachment

Evelyn C. Ferstl
Department of Psychology
University of Colorado at Boulder
Boulder, Colorado 80309-0345
eferstl@clipr.colorado.edu

Abstract

Two experiments are reported to test whether the location of prepositional phrase attachment can be influenced by syntactic and contextual factors. The first experiment tested the hypothesis that attachment is delayed until the word after the prepositional phrase. Replicating the results of Taraban and McClelland (1988), this experiment showed that sentence bias rather than syntactic structure determines the ease of processing; attachment effects were observed on the words after the noun filler. In addition, using sentences in which the noun filler consisted of a compound noun, we also found evidence for delayed attachment. Using sentences in which the noun filler was modified by an adjective, we found evidence for early attachment. In the second experiment, we used context paragraphs to induce earlier attachment for the compound noun sentences. When the first noun of the compound was mentioned in the prior discourse, attachment effects were observed on the disambiguating noun filler. When the first noun was not mentioned, attachment effects were observed, as in Experiment 1, on the words after the prepositional phrase. Thus, the study supports the idea of a context-dependent delay strategy for prepositional phrase attachment.

Introduction

The question of how pragmatic information and discourse context influence syntactic processing has recently received much attention. According to the modularity hypothesis (Fodor, 1983), syntactic processing is informationally encapsulated and can not be directly influenced by non-syntactic knowledge. Based on this view, syntax-first models postulate that syntactic principles (e.g., Frazier & Rayner, 1982) are used to derive the initial sentence structure. Non-syntactic information is then considered in a second processing stage to evaluate the plausibility of the resulting interpretation. Interactive models, on the other hand, presume that all knowledge sources are taken into account in parallel (e.g., Marslen-Wilson & Tyler, 1980; McClelland, 1987; Crain & Steedman, 1985). Both types of models grant the eventual impact of pragmatic information on the correct interpretation of an utterance. Thus, they can be distinguished only by identifying the exact location at which non-syntactic factors exert their influence.

One of the syntactic ambiguities used to study the interaction between the syntactic structure of the sentence and pragmatic knowledge is prepositional phrase attachment. Consider the sentences:

1) Catherine cut up the shirt with the *knife* because she needed some rags.
2) Catherine cut up the shirt with the *pocket* because she needed some rags.

In the first sentence, the prepositional phrase specifies the instrument of the action *cutting*, and is thus attached to the verb of the sentence. In the second sentence, the prepositional phrase modifies the object of the sentence, and is thus attached to the noun *shirt*. Successful selection of the appropriate syntactic interpretation can only be accomplished when the meaning of the noun filler and its relation to the sentence is taken into account. Using sentences of this type, Frazier and Rayner (1982) provided evidence for a syntax-first model. They showed that, in accordance with the principle of minimal attachment, the noun attachment reading was more difficult to process than the verb attachment reading. In contrast, Taraban and McClelland (1988) showed that, independent of the syntactic structure, the interpretation was more difficult which was inconsistent with the sentence bias. Providing further support for an interactive model, Altmann and Steedman (1988) and Britt, Perfetti, Garrod, & Rayner (1992) embedded the sentences in biasing context paragraphs. In these studies, reading difficulties were observed for the attachment which was inconsistent with the discourse bias.

Although these latter three studies agree in indicating that pragmatic knowledge and discourse context predict processing difficulties better than syntactic principles, they leave an important question open. The results did not converge with respect to the location of the processing differences. Altmann and Steedman (1988), using a cumulative self-paced reading task, and Britt et al. (1992, Experiment 2), using eye-movement monitoring, found reading time differences in the disambiguating prepositional phrase, i.e., early effects of non-syntactic information. Britt et al. (1992, Experiment 1) and Taraban and McClelland (1988), both using non-cumulative self-paced reading tasks,

found differences only in the region *after* the prepositional phrase, but not on the disambiguating noun filler itself.

Two explanations can be put forth to explain this discrepancy. First, it has been argued that reading time measures are highly task dependent. Increased reading times for inconsistent sentences could be due to a spill-over effect, and thus reflect processing difficulties on previous words rather than on the current one. Second, and more interestingly, it has been proposed that attachment might in some cases be delayed. Attachment might not be attempted before a "trigger" is encountered (Perfetti, 1990), or before the following word makes it clear that the prepositional phrase is completed (Taraban & McClelland, 1988).

To address these two issues, we conducted two experiments. The first goal was to show that the non-cumulative, self-paced reading task is sufficiently sensitive to capture processing difficulties immediately. The second objective was to identify factors which trigger attachment. Possible triggers considered in this study were the complexity of the noun phrase, and the repetition of a word from the prior discourse. The crucial sentences used in contained a compound noun as the noun filler of the prepositional phrase. If attachment was attempted immediately, this additional local ambiguity should lead to a garden-path, independent of the attachment or sentence preference. If the complexity of the noun phrase (i.e., the noun phrase including a modifier) triggered integration of the PP into the sentence structure, attachment effects would be expected in the disambiguating phrase. Finally, if attachment was delayed until the word following the prepositional phrase, then reading time patterns for the compound noun sentences would be expected to be similar to those for sentences containing a simple noun phrase.

Experiment 1

The first experiment was designed to test whether attachment takes place immediately upon encountering the noun filler in the prepositional phrase. Sentences were used in which the first noun after the preposition was *not* the noun filler, but an adjectival modifier. In one condition the noun filler consisted of a compound noun, so that both nouns alone were meaningful continuations of the sentence, while requiring different attachments. Thus, parsing these compound noun sentences required disambiguating the lexical category of the first noun as well as disambiguating the prepositional phrase. In a second condition, the modifier was an unambiguous adjective. As in Taraban and McClelland (1988), both attachment and sentence preference were independently manipulated. We also included sentences with simple noun phrases for which we expected to replicate Taraban's and McClelland's results.

Method

Forty-two undergraduate students from the University of Colorado participated in the experiment for course credit. They were all native speakers of English.

Thirty-two sentences were written which contained a compound noun as the noun filler of the prepositional phrase. Each sentence appeared in the following four versions:

Simple noun phrase (version 1):
The exterminator sprayed the porch with the *poison.*
Simple noun phrase (version 2):
The exterminator sprayed the porch with the *ivy.*
Compound noun phrase (version 3):
The exterminator sprayed the porch with the *poison ivy.*
Adjective noun phrase (version 4):
The exterminator sprayed the porch with the *lush ivy.*

The fourth version, containing an adjective instead of the first noun of the compound, was added as an unambiguous control for the complexity of the compound noun phrase in Version 3.

Each sentence was labelled according to whether the compound noun (version 3) required a verb attachment or a noun attachment. Thus, the example given above is labelled a noun attachment sentence, although Version 1 requires a verb attachment. The sentences were pretested using a Cloze task to ensure that eight sentences were in each of the four cells of the Attachment x Preference design. Examples for sentences in each of the conditions are:

verb attachment, verb preference:
The little boy won a pound of cookies in a sack race.
verb attachment, noun preference:
The social worker suggested a solution to the problem child.
noun attachment, verb preference:
The exterminator sprayed the porch with the poison ivy.
noun attachment, noun preference:
The police arrested the mastermind behind the bank robbery.

To each sentence, a continuation was written so that the prepositional phrase was followed by at least three words.

The word frequencies of the nouns were comparable across conditions. Eight lists of the experimental sentences were created in which the sentence version was counterbalanced across the four conditions. The order of the sentences was randomized for each subject, and 64 filler sentences were randomly inserted.

The 96 sentences, and 5 practice sentences, were presented in a non-cumulative moving-window technique (Just, Carpenter & Woolley, 1982). At the start of a trial, all letters of the sentence were replaced by dashes, leaving the spaces between words intact. Subjects used the space bar to request the display of each word. At the button press, the current word was replaced by dashes, and the next word in the sentence was displayed. Reaction times were measured for each button press to yield word reading times. To ensure proper comprehension, the subjects were asked to paraphrase the sentence after 24 randomly selected trials.

Results

All word reading times were truncated at 2500 msec. To control for word length, and to control for individual differences, the reading times from the filler sentences were used to calculate linear regression coefficients for each subject, using word length as a predictor of reading time. For the experimental sentences, residuals from these regressions were used as the dependent variable in all analyses. The four crucial positions within the sentences

were the (first and) second word of the noun phrase in the prepositional phrase, and the two words following the noun phrase. All analyses were conducted over subjects (F-values are denoted with F1) and over items (F2). In the analysis by subjects, all three factors Attachment, Preference, and Sentence Version were within-subjects. In the analysis by sentences the factors Attachment and Preference were between-items, while the factor Version was within-items.

Simple NP sentences: The noun filler was read slightly faster for sentences in Version 2 (the second word of the compound noun) than for sentences in Version 1 (the first word of the compound noun), yielding a significant main effect of Version ($F1(1,41)=4.3$, $p<0.05$, $F2(1,28)=9.18$, $p<0.01$). Neither Attachment nor Preference influenced reading times at this position.

For the word after the prepositional phrase, there was a highly significant triple interaction between Attachment, Preference and Version ($F1(1,41)=14.9$, $p<0.001$, $F2(1,28)=9.4$, $p<0.01$), indicating that this word was read faster in sentences in which the attachment was consistent with the sentence preference. Processing times tended to increase more when a verb preference was violated than when a noun preference was violated. Thus, the Attachment x Version interaction reached significance by subjects ($F1(1,41)=4.9$, $p<0.05$) and almost by items ($F2(1,28)=4.1$, $p<0.06$).

At the second word after the prepositional phrase the advantage for consistent sentences was still significant ($F1(1,41)=18.0$, $p<0.0001$, $F2(1,28)=13.8$, $p<0.001$). No other effect was found on this position.

Complex NP sentences: In the overall analysis for these sentences, no effects of either attachment or preference were found. To evaluate the effects of consistency, we report here only the results of planned comparisons. For each word and each of the two sentence versions, we tested whether there was a consistency effect; i.e., we tested whether reading times for sentences in which Attachment and Preference matched were longer than reading times for sentences in which the Attachment was different from the Preference.

For compound noun sentences, there were significant consistency effects on both words after the prepositional phrase ($F1(1,41)=10.0$, $p<0.01$, $F2(1,30)=6.8$, $p<0.05$, for the first word; $F1(1,41)=10.8$, $p<0.01$, $F2(1,30)=5.0$, $p<0.05$, for the second word), but not before (all $F's<1$).

For the adjective sentences, the consistency effect on the adjective was reliable ($F1(1,41)=8.2$, $p<0.01$; $F2(1,30)=15.5$, $p<0.001$). Increased processing times were also observed on the noun filler itself ($F1(1,41)=6.3$, $p<0.05$), although this result was not significant by sentences ($F2(1,30)=2.1$, $p=0.16$).

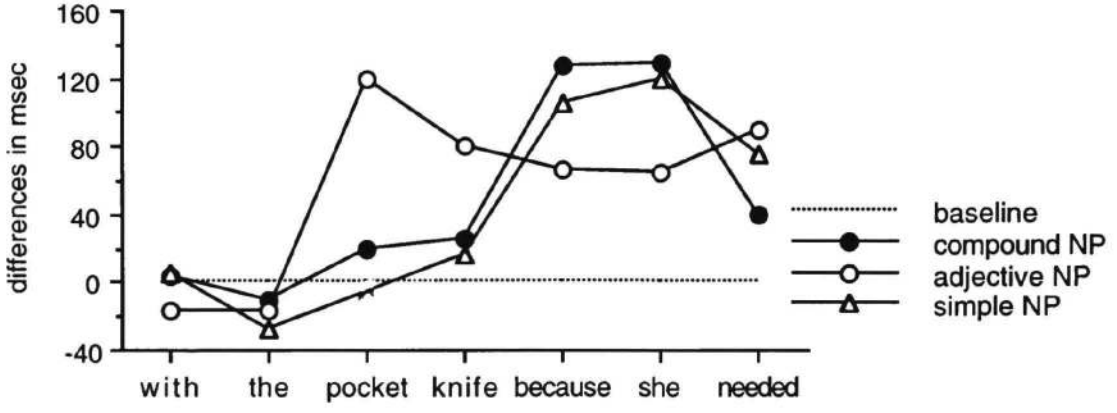

Figure 1. Differences between inconsistent and consistent sentences for each of the sentence types. The curve labelled "simple NP" is averaged across Version 1 and Version 2 sentences.

Discussion

The results for the simple noun phrase sentences replicated those of Taraban and McClelland (1988). Consistency with sentence preference, not attachment, predicted processing difficulties on the words after the prepositional phrase. No attachment effects were found on the disambiguating noun filler of the prepositional phrase.

Reading time patterns for the sentences which contained a compound noun filler mirrored those for the simple NP sentences almost perfectly. There was no indication for a garden-path induced by the additional local ambiguity in these sentences. Attachment was delayed until the word following the prepositional phrase signaled the end of the noun phrase. Thus, the complexity of the noun phrase alone does not trigger earlier attachment.

For the sentences in which an adjective was added in the prepositional phrase, processing times increased reliably on the adjective, even before the disambiguating noun. This result shows that the self-paced reading task is sufficiently sensitive to capture processing difficulties immediately. Moreover, the diminished consistency effects on the words following the adjective suggest that processing the unexpected adjective allowed readers to anticipate the inconsistent attachment upon processing the adjective.

Experiment 2

The second experiment was designed to induce earlier attachment of the compound noun phrases. To each sentence, contexts consisting of one or two sentences were written. The two contexts were minimally different in the sense that only one word or a short phrase was altered. In one context, the first noun of the compound (e.g., *poison*) was mentioned, in the other context this word was replaced by a neutral word. For example, the two contexts used for the *poison ivy* sentence are:

Mention context:

1) The Gordons avoided using *poison* whenever possible. When they found lice on their porch, they had to call an exterminator.

No-mention context:

2) The Gordons avoided using *chemicals* whenever possible. When they found lice on their porch, they had to call an exterminator.

The contexts were not intended to bias towards either attachment. However, finding the first noun (e.g., *poison*) in the discourse context was hypothesized to trigger earlier attachment (e.g., Perfetti, 1990; Altmann & Steedman, 1988) for sentences in Version 1 (*poison*) and Version 3 (*poison ivy*). For the other two sentence types (i.e., *ivy* and *lush ivy*) no effects of context were expected.

Method

Fifty-four subjects participated in this experiment. The same 32 sentences were used as in Experiment 1. The factors Attachment and Preference were collapsed into one factor Consistency. To each sentence two short context paragraphs, consisting of one or two sentences, were written (see above). Each subject saw two paragraphs in each of the cells of the Consistency x Version x Context design. Because the paragraphs were longer, only 40 filler trials were randomly inserted between the experimental trials. The procedure was identical to that of Experiment 1, except for the comprehension test. In order to encourage integration of the target sentence with the preceding context sentences, subjects were asked to summarize the paragraph in one short sentence.

Results

Reading times were truncated at 2500 msec. As in Experiment 1, the analyses are based on the residuals from the individual regressions of reading times on word lengths. Instead of reporting the results of the overall analyses, we focus here on the planned comparisons. For each sentence version and each context, the question of interest was at which location the consistency effect was first observed.

Simple NP sentences. Figure 2 shows the consistency effect for Version 1 sentences as a function of context. When the noun filler of these sentences was mentioned in the context, the consistency effect manifested itself at the word immediately following the prepositional phrase ($F1(1,53)=15.0$, $p<0.001$, $F2(1,30)=9,5$, $p<0.01$). When the noun filler was not mentioned, there was no consistency effect on the word immediately following the prepositional phrase ($F's<1.8$), but on the next word ($F1(1,53)=13.5$, $p<0.001$, $F2(1,30)=7.6$, $p<0.01$). For Version 2 sentences, the consistency effect on the word after the prepositional phrase was significant in both contexts ($F1(1,53)=9.4$, $p<0.01$; $F2(1,30)=4.0$,$p<0.06$, for Context 1; $F1(1,53)=6.7$, $p<0.01$, $F2(1,30)=4.4$, $p<0.05$, for Context 2).

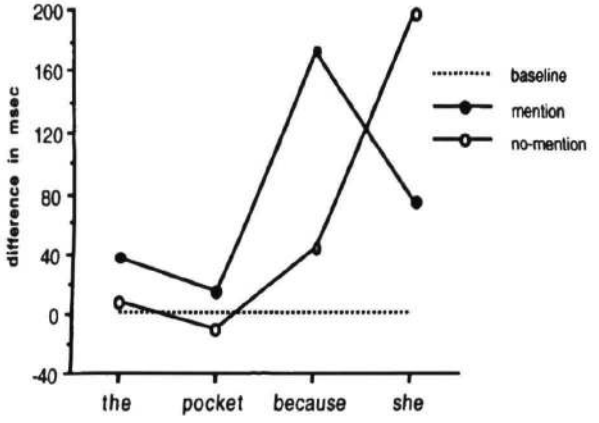

Figure 2: Consistency effect as a function of context for the simple noun sentences in Version 1 (*pocket, poison*).

Complex NP sentences. Figure 3 illustrates the consistency effect for the compound noun sentences. When the compound noun sentences were embedded in the context which did not mention the first noun, the consistency effect appeared on the word after the prepositional phrase ($F1(1,53)=17.0$, $p<0.0001$; $F2(1,30)=11.8$, $p<0.002$), but not before ($F's<1$). However, when the first word of the noun filler was mentioned in the context, there was a consistency effect on the second word of the noun filler ($F1(1,53)=10.1$, $p<0.01$; $F2(1,30)=5.5$, $p<0.05$).

For the adjective sentences, consistency did not affect reading times for the adjective in either context. Embedded in Context 1, the consistency effect reached significance only by subjects ($F1(1,53)=5.0$, $p<0.05$, for the noun filler, $F1(1,53)=5.6$, $p<0.05$, for the word after the PP), but never by items ($F2(1,30)=1.7$, $p=0.21$, and $F2(1,30)=2.7$, $p=0.11$, resp.). Embedded in Context 2, there was a reliable consistency effect for the noun filler ($F1(1,53)=14.8$, $p<0.001$; $F2(1,30)=6.2$, $p<0.05$).

Discussion

The context paragraphs did not alter the sentence preferences differentially. For all sentence types, consistent sentences were read faster than inconsistent sentences. The location of the consistency effect changed, however. The repetition of a word from the prior discourse could indeed influence the location of attachment. When the noun filler, or the first word of the compound noun filler, was mentioned in the preceding context, attachment difficulties were observed one word earlier than when the noun was not mentioned. Thus, finding a referent for one of the words in the noun phrase triggered attachment. For the adjective sentences, the

consistency effect appeared later in context than in isolation, and its magnitude was diminished.

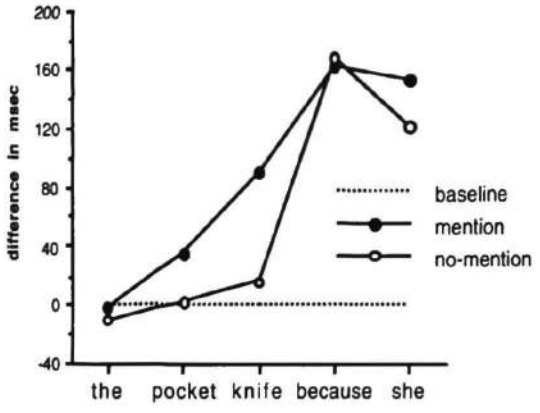

Figure 3: Consistency effect as a function of context for the compound noun sentences.

General Discussion

The experiments reported here allows several conclusions. First, it was shown that the self-paced reading task can be used to detect attachment difficulties immediately. Early effects in Experiment 1 for the adjective sentences, and in Experiment 2 for the compound noun sentences showed that the reading time measure is sensitive enough for capturing processing difficulties immediately. There was no evidence for a general spill-over effect.

Second, attachment did not predict reading time differences. In support of an interactive model, the consistency of the attachment with the sentence preference determined the ease of processing (for a possible syntactic account of the cause of the preferences, see Clifton, Speer & Abney, 1989).

Third, the study provides evidence for a context-dependent delay strategy in prepositional phrase attachment. Using only minimally different sentences, both early and late attachment effects were observed. Experiment 1 replicated the late effects found by Taraban and McClelland (1988), and extended them to compound noun sentences. Even in these sentences with increased complexity of the noun phrase, containing a modifier, attachment was delayed until after the end of the phrase. No evidence for a garden-path induced by the additional local ambiguity of these sentences was obtained. This result is incompatible with a parsing model in which each word is assumed to be integrated into the sentence structure as it is encountered.

Fourth, somewhat surprising results were obtained for the adjective sentences. These sentences were merely intended to provide a control condition for the length of the compound noun phrase, and were expected to be processed like the simple noun phrases. Contrary to these expectations, the consistency of attachment and sentence preference affected the reading times even before the noun filler was read. Attachment of adjective sentences was initiated before encountering the lexical head of the phrase. Therefore, a head-corner parser (e.g., Abney, 1989) seems to be inconsistent with the present results (cf., Hemforth, Konieczny, & Strube, 1993, who reported a similar finding). Although a left-corner parser (Johnson-Laird, 1983) can account for the early effects for the isolated adjective sentences, it does not explain how the discourse context eliminated these effects.

Fifth, referential information was shown to change the location of attachment. When the noun filler in the prepositional phrase had been referred to in the prior discourse, consistency effects were observed earlier than when it had not been mentioned. This result is consistent with the early effects found by Altmann and Steedman (1988), who also used context paragraphs in which the noun filler was mentioned. Context did influence the parsing processes immediately.

These results suggest that a successful theory of parsing must specify in detail the interactions between local processes, such as lexical category assignment, and global processes, such as constituent phrase attachment. Attempts to refine parsing theories in this way have been made. For instance, Frazier & Rayner (1987) modified their garden-path theory. They postulate a delay mechanism for lexical category assignment, and a first-available strategy for global structural decision. Delayed category assignment, and consequently delayed prepositional attachment, is consistent with the late consistency effects from Experiment 1. However, the modified garden-path model does predict processing difficulties for non-minimal attachment sentences, rather than processing difficulties for unexpected attachments. Furthermore, this model cannot account for the context effects obtained in Experiment 2.

In contrast to the modified garden-path model, Perfetti (1990) suggested immediate assignment of lexical categories, but delayed global attachments. The global attachments can be triggered by syntactic, semantic, and contextual information. This framework seems to be most easily adopted for explaining the data from the current study. In isolation, the word after the prepositional phrase triggers attachment, and in the discourse context, the previously mentioned noun acts as a trigger. However, it is necessary to compile a complete list of the possible triggers in order to evaluate the predictions of this theory.

Finally, strongly interactive models are compatible with our results. For instance, the probabilistic model proposed by MacDonald (1993), explains parsing processes using statistical information about syntactic and non-syntactic constructions. To account for the present data it would be necessary to obtain detailed information about the relative frequencies of occurrence of the sentence types used in this study.

Further empirical research is needed to understand the interplay between syntactic mechanisms on various levels, as well as their interaction with non-syntactic information. We hope that the present study contributes to this understanding, so that we can come closer to an accurate description of human language processing system.

Acknowledgments

I am grateful to Walter Kintsch for his advice on this work. Murray Singer and three anonymous reviewers made valuable comments on an earlier draft of this paper.

References

Abney, S. P. (1989). A computational model of human parsing. Journal of Psycholinguistic Research, 18, 129-144.

Altmann, G. T. M., & Steedman, M. (1988). Interaction with context during human sentence processing. Cognition, 30, 191-238.

Britt, M. A., Perfetti C. A., Garrod, S., & Rayner, K. (1992). Parsing in discourse: Context effects and their limits. Journal of Memory and Language, 31, 293-314.

Clifton, C., Jr., Speer, S., & Abney, S. P. (1991). Parsing arguments: Phrase structure and argument structure as determinants of initial parsing decisions. Journal of Memory and Language, 30, 251-271.

Crain, S., & Steedman, M. (1985). On not being led up the garden path: The use of context by the psychological syntax parser. In D. R. Dowty, L. Karttunen, & A. M. Zwicky (Eds.), Natural language parsing: Psychological, computational, and theoretical perspectives (pp. 320-358). Cambridge: Cambridge University Press.

Fodor, J. A. (1983). The modularity of mind. Cambridge, MA: MIT Press.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. Cognitive Psychology, 14, 178-210.

Frazier, L., & Rayner, K. (1987). Resolution of syntactic category ambiguities: Eye movements in parsing lexically ambiguous sentences. Journal of Memory and Language, 26, 505-526.

Hemforth, B. Konieczny, L., & Strube, G. (1993). Incremental syntax processing and parsing strategies. In The Proceedings of the 15th Annual Meeting of the Cognitive Science Society. Hillsdale, NJ: Lawrence Erlbaum Associates.

Johnson-Laird, P. N. (1983). Mental Models. Cambridge, MA: Harvard University Press.

Just, M. A., Carpenter, P. A., & Woolley, J. (1982). Paradigms and processes in reading comprehension. Journal of Experimental Psychology: General, 111, 228-238.

Marslen-Wilson, W. D., & Tyler, L. K. (1980). The temporal structure of spoken language understanding. Cognition, 8, 1-71.

MacDonald, M. C. (1993). The interaction of lexical and syntactic ambiguity. Journal of Memory and Language, 32, 692-715.

McClelland, J. L. (1987). The case for interactionism in language processing. In M. Coltheart (Ed.), Attention and performance XII: The psychology of reading (pp. 3-38). Hillsdale, NJ: Lawrence Erlbaum Associates.

Perfetti, C. A. (1990). The cooperative language processor: Semantic influences in an autonomous syntax. In D. A. Balota, G. B. Flores d'Arcais, & K. Rayner (Eds.), Comprehension processes in reading (pp. 205-230). Hillsdale, NJ.: Lawrence Erlbaum Associates.

Taraban, R., & McClelland, J. L. (1988). Constituent attachment and thematic role assignment in sentence processing: Influences of content-based expectations. Journal of Memory and Language, 27, 597-632.