Context Effects in Syntactic Ambiguity Resolution: Discourse and Semantic Influences in Parsing Reduced Relative Clauses

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Abstract This article examines how certain types of semantic and discourse context affect the processing of relative clauses which are temporarily ambiguous between a relative clause and a main clause (e.g., "*The actress selected* by the director..."). We review recent results investigating local semantic context and temporal context, and we present some new data investigating referential contexts. The set of studies demonstrate that, contrary to many recent claims in the literature, all of these types of context can have early effects on syntactic ambiguity resolution during on-line reading comprehension. These results are discussed within a "constraint-based" framework for ambiguity resolution in which effects of context are determined by the strength and relevance of the contextual constraint and by the availability of the syntactic alternatives.

Résumé Le présent article porte sur les effets qu'ont certains types de contextes sémantiques et propres au discours sur le traitement de propositions relatives qui sont temporairement ambiguës (p. ex. «*The actress selected* by the director...»). Nous examinons les résultats obtenus récemment au sujet du contexte sémantique et du contexte temporel et nous présentons de nouvelles données sur les contextes référentiels. Il ressort de la série d'études que, contrairement à maintes affirmations récentes dans la littérature, tous ces types de contextes peuvent influer dès le début sur la résolution d'ambiguïtés syntaxiques pendant la lecture en temps réel. Les résultats sont traités selon un cadre basé sur des contraintes pour la résolution d'ambiguïtés, dans lequel les effets contextuels sont déterminés par la force et la pertinence des contraintes liées au contexte ainsi que par la présence de choix syntaxiques.

Language comprehension takes place rapidly and, to a first approximation, incrementally. As the linguistic input is received, readers and listeners update representations that take into account information from the sentence and information from the discourse (Marslen-Wilson, 1973). The on-line nature of comprehension has important consequences for syntactic processing. First,

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developing even a provisional interpretation requires making some syntactic commitments. Thus, readers will have to make at least partial syntactic commitments at points in a sentence where the input underdetermines the syntactic structure. These commitments will have to be revised if they turn out to be inconsistent with subsequent input. Clear examples arise when readers experience a conscious confusion or "garden-path", as in Bever's (1970) famous sentences with reduced relatives, examples of which are illustrated in:

1. a. The horse raced past the barn fell
   b. The boat floated down the river sank.

A second consequence of on-line interpretation is that readers will have information available from the preceding context that could be used to constrain the syntactic alternatives at points of local indeterminacy. How and when the language processing system makes use of this information is currently the focus of extensive research. The underlying theoretical question is often cast as one about the architecture of the language processing system. In particular, does the architecture of the system restrict the types of information that can be used in syntactic ambiguity resolution?

The research reported here uses sentences with reduced relative clauses to investigate how different types of contextual information are used in ambiguity resolution. We will be summarizing some recent results and reporting new experimental data on the use of (a) local semantic constraints on verb arguments; and (b) pragmatic/referential information from the discourse. Each of these types of information has played an important role in current discussions of parsing and, more generally, about the architecture of the language processing system. Contrary to many findings in the literature, we report evidence that both types of information have clear and immediate effects on ambiguity resolution. However, these effects depend upon the bottom-up availability of the syntactic alternatives. This helps explain why the literature on these topics has produced somewhat inconsistent results. Before we turn to the details of this research, we will first describe the reduced relative clause ambiguity and the types of contextual information that we will be exploring. We then present a brief overview of the different types of approaches to syntactic ambiguity resolution that are currently being explored in the literature.

Reduced Relative Clauses

In English, reduced relative clauses are frequently ambiguous because the same verb form, usually verb + "ed", is used for both the past tense and the participial forms of most verbs. Thus, a fragment beginning with a noun followed by a verb + "ed" will be ambiguous between the start of a main clause and the start of a relative clause. In a main clause, the noun phrase is

the subject of the verb, whereas in a relative clause, the noun phrase is the logical object of the verb.

As the examples in (2) illustrate, readers have a clear bias in favour of treating an ambiguous fragment as a main clause. Numerous empirical studies have demonstrated that readers experience difficulty as soon as they encounter *syntactic information that disambiguates the fragment as a relative clause* (e.g., Ferreira & Clifton, 1986; Rayner, Carlson, & Frazier, 1983). For example, reading times will be longer to the disambiguating agentive "by"-phrase in (2a) than in the unambiguous (2b) or (2c).

2. a. The scientist selected by the committee was later fired.
   b. The scientist who was selected by the committee was later fired.
   c. The scientist chosen by the committee was later fired.

There are a variety of explanations for why this preference exists. Bever (1970) proposed that readers and listeners adopt frequency-based perceptual strategies for predicting clause boundaries and recovering deep-structure relationships. A verb + "ed" form that immediately follows a noun is far more likely to be a past tense verb than a participial, especially at the beginning of a sentence (cf. Tabossi, Spivey-Knowlton, McRae, & Tanenhaus, 1993). Frazier (1978) accounts for the main clause preference in terms of syntactic simplicity using the Minimal Attachment Principle, which states that the parser prefers to attach a word using the fewest possible nodes consistent with the phrase structure rules of the language. A relative clause has more nodes because it is a sentence embedded within a noun phrase, whereas a main clause is just a simple sentence. Crain and Steedman (1985) propose an explanation in terms of conceptual simplicity. In the absence of specific information in the discourse, the pragmatic presuppositions associated with a restrictive relative clause are more complex than those for a main clause.

The reduced relative clause has been a useful structure for examining the role of context in ambiguity resolution for several reasons. First, as we have seen, it has a clear unambiguous baseline condition, either a full (unreduced) relative clause, such as (2b), or preferably an unambiguous relative clause such as (2c). Second, the ambiguity is local, as is the point at which the sentence is disambiguated. Third, in the absence of context, there is a strong preference for one of the syntactic alternatives. This would make evidence for context effects quite compelling. Finally, using relative clauses allows one to explore a variety of different types of context using the same structure, and in some cases the same sentences. This makes it possible to compare the time course with which different types of information are used in sentence processing, while holding local factors constant.

There are two broad classes of constraint that are directly relevant to the reduced relative/main clause ambiguity. Each of these types of constraint is

quite general, i.e., relevant to a wide range of syntactic ambiguities. The first is the semantic fit of a noun phrase to a potential argument position. The subject noun phrase in a main clause typically plays the thematic role of Agent in the event denoted by the verb, whereas the noun phrase in a reduced relative clause is the Theme or Patient. Thus, the semantic fit of the noun as an Agent and as a Patient of the ambiguous verb would be a relevant source of constraint. Consider, for example the fragments in (3):

3. a. The evidence examined...
   b. The scientist examined...

"Evidence" is an implausible Agent of an "examining" event, but a plausible Theme, whereas "scientist" is a highly plausible Agent and a less plausible Theme. Therefore the fragment in (3a) is more likely to begin a reduced relative clause, whereas the fragment in (3b), is more likely to begin a main clause.

The second type of constraint is the relationship between the sentence and the prior discourse. Definite noun phrases typically refer to entities that have already been introduced into a discourse. Main clauses introduce new events into the discourse, whereas restrictive relative clauses often disambiguate among a set of possible referents. A processing system that is incrementally updating a model of the events and entities in the discourse might attempt to immediately establish the referent of the noun phrase. Whether a unique referent or a set of possible referents was available would then be relevant to the likelihood that the ambiguous structure was a main clause or a relative clause. Note that a fragment that has a main clause bias when it is preceded by a context with a unique referent (e.g., one scientist) has a strong relative clause bias when it is preceded by a context that introduces a set of referents (e.g., two scientists) (Crain, 1980; Crain & Steedman, 1985).

Current approaches to ambiguity resolution differ in how they make use of contextual information. For purposes of simplicity, we will divide recent proposals into three categories: Two-stage approaches, discourse-based approaches, and constraint-based approaches.

Two-stage models

Two-stage models assume that parsing proceeds serially, with only one structure under active consideration. During the first stage of parsing, a *restricted* domain of syntactically-relevant information is used to posit an initial structure. This structure is then evaluated and, if necessary, revised. The evaluation and revision stage can make use of information that was not used in initial structure building. The best-known model in this category is the "garden-path" model originally proposed by Frazier and Rayner (1982). In the most current version of the model, initial structure building is guided by a

small set of maximally general attachment principles (Minimal Attachment and Late Closure) which are defined over syntactic categories. Thus, an initial structure can be built rapidly using a limited domain of information. Garden-paths occur whenever the structure of a sentence turns out to be inconsistent with the attachment principles. According to this model, both local semantic constraints and discourse constraints, as well as lexically-specific syntactic constraints, can affect the evaluation and revision stage of parsing, but not the initial structure building stage. Thus, the garden-path model would predict that the effects of either semantic fit or discourse context would be delayed for architectural reasons.

Discourse-based models

According to this class of models, ambiguity resolution is guided by syntactically-relevant information from the discourse. This information is pragmatic in that it is tied to the discourse function of syntactic structures. Discourse-based constraints can guide ambiguity resolution because the discourse model is being continuously updated as the information in a sentence is processed. The best developed model in this category is the referential theory originally proposed by Crain and Steedman (1985) and further developed by Altmann and Steedman (1988) and Ni and Crain (1990). According to the referential theory, syntactic analyses are developed in parallel. The structure whose pragmatic presuppositions are best satisfied by the discourse is then rapidly selected. In the absence of appropriate information in the discourse model, the structure requiring the fewest additional presuppositions is chosen. Most of the work in the theory is accomplished by referential mechanisms, as will be developed in more detail later. Garden-paths occur whenever a local ambiguity is resolved in favour of the alternative requiring the most additional presuppositions. The referential theory predicts that appropriate discourse contexts can reverse syntactic preferences. Thus, it predicts immediate effects of discourse context. However, local factors, such as argument fit, are not assigned any weight by the theory.

Constraint-based approaches

Constraint-based, or "evidential", approaches treat syntactic ambiguity resolution as a constraint-satisfaction problem (e.g., Bates & MacWhinney, 1989; McClelland, St. John, & Taraban, 1989) in which different constraints provide evidence in support of partially activated alternatives. In current structurally-driven variants, in which "bottom-up" information defines the "search" space, syntactic alternatives will be more or less active depending upon how consistent they are with the input (e.g., MacDonald, 1992; Tabossi, et al., 1993; Trueswell, Tanenhaus, & Garnsey, 1992). For example, the more frequent alternative given the input will become activated more rapidly.

Salient (currently active) contextual information that is correlated with the alternatives can provide biasing evidence. Ambiguity resolution is viewed as continuous. Both local semantic context and discourse context will have strong and immediate effects when the relevant alternatives are active and the constraint is strong. They will have weak and/or delayed effects when the constraints are weak or when the alternative that they are biased in favour of is only weakly activated. Conscious garden-paths occur when an alternative that is strongly supported by the initial evidence later turns out to be incorrect and the correct alternative is no longer active.

Each class of model makes different predictions about the processing of fragments that are temporarily ambiguous between a main clause and a relative clause. Two-stage models, such as the garden-path model, predict that the main clause structure will be the only structure initially computed because it is the syntactically simplest alternative. The referential theory predicts that both alternatives will be equally available. The alternative that best fits the context or involves the fewest presuppositions will be chosen. Finally, the constraint-based approach predicts that the main clause alternative will be more active initially, because it is the more frequent structure given the input; however, strong contextual constraints will come into play immediately.

LOCAL SEMANTIC CONTEXT

The issue of whether the semantic content of words influences initial parsing decisions plays an important role in distinguishing among various approaches to sentence processing. Proponents of constraint-based models would argue that when this kind of information places clear restrictions on grammatical relations among constituents, these restrictions could in turn constrain on-line parsing commitments. For example, verbs often place semantic constraints on the nouns that they allow in subject and object positions. The question arises: will such constraints determine which alternative is computed in the case of a syntactic ambiguity? Ferreira & Clifton (1986, Experiment 1) monitored eye-movements while subjects read sentences with relative clauses such as (4):

4. a. The defendant examined by the lawyer turned out to be unreliable.
   b. The defendant that was examined by the lawyer turned out to be unreliable.
   c. The evidence examined by the lawyer turned out to be unreliable.
   d. The evidence that was examined by the lawyer turned out to be unreliable.

The first noun in the sentence was either animate or inanimate. Recall that animate nouns are typically plausible Agents, whereas inanimate nouns are implausible Agents but plausible Themes. The first noun in a main clause is likely to be the Agent whereas, the first noun in a reduced relative clause is likely to be the Theme. Therefore, the animacy of the noun provides

information that would be relevant to resolving the ambiguity.

A two-stage restricted domain processor, or a *pure* discourse-based processor, would ignore constraints of this kind. In (4a) and (4c), the simplest structure, and the structure having the least discourse presuppositions, is the main clause rather than the relative clause. Thus, on either approach, the processor would be equally likely to incorporate "The defendant" or "The evidence" as the subject (or Agent) of "examined".

Ferreira and Clifton (1986) found two important results. First, reading times to the verb following an inanimate noun were elevated for the reduced relatives, suggesting that the animacy information was available. Second, both first and second pass reading times in the "by"-phrase region were elevated in the reduced relatives (4a & 4c) as compared to the unambiguous unreduced relative clauses (4b & 4d) regardless of animacy. This reduction effect suggests that the semantic information was not used in parsing. While these results would appear to provide definitive evidence in support of two-stage models in which initial commitments are made without reference to semantic information, recent work from our laboratory suggests a different story.

Trueswell et al. (1992) conducted two eye-tracking experiments that were similar in design to Ferreira and Clifton (1986), but with modified materials. Ferreira and Clifton's materials included inanimate nouns that did not rule out a main clause continuation with the ambiguous verb (e.g., "the trash smelled..." or "the car towed..."), and a variety of different types of prepositional phrases. In Trueswell et al.'s first experiment, only inanimate nouns that ruled out a congruous main clause continuation were used. In addition, the disambiguating prepositional phrase was always an agentive "by"-phrase, providing an explicit Agent for every relative clause. Trueswell et al. found clear effects of animacy. First pass and second pass reading times to the "by"-phrase were longer to reduced relative clauses compared to unambiguous controls when the noun was animate but not when it was inanimate.

This pattern of results was then replicated using materials developed by Burgess (1991). Burgess (Burgess, 1991; Burgess & Tanenhaus, 1992) used completion norms to select inanimate noun-verb fragments that were typically completed as relative clauses (e.g., The evidence examined...). In a self-paced reading study in which *two word* segments were presented using a moving window (e.g., /The evidence/ /examined by/), Burgess found the same pattern of results as Trueswell et al., namely an interaction between animacy and clause type. However, with a *one word* moving window, Burgess found exactly the same pattern of results as Ferreira and Clifton (1986), that is, longer reading times at the verb for inanimates with reduced relative clauses and no interaction between animacy and reduction at the "by"-phrase. In addition, Burgess did not find an interaction with animacy using either a one-word window or a two-word window with Ferreira and Clifton's materials.

The pattern of data across studies can be explained by a simple generalization. Animacy had clear effects when (a) it provided a strong constraint and (b) both the past-tense and the participial forms of the ambiguous verb were sufficiently activated. The participial form was substantially available, however, only when the reader could see the "by", either parafoveally in unrestricted reading, where a short high frequency function word such as "by" typically does not require a separate fixation (Trueswell et al., 1992), or with a two-word window in which the verb and "by" were presented together. The parafoveal preview of "by" during fixation of the verb provides probabilistic information (the Agentive use of "by") that supports a relative clause structure. This information counteracts the strong asymmetry in availability between the highly frequent main clause structure and the less frequent reduced relative clause structure.

Note also that the segmentation that Burgess used with the relative clause structure, which pairs a function word and a content word, groups together just those words that would normally be processed on the same fixations.[1] This similarity in segmentation and the similarity in experimental results support the claim that, with the reduced relative ambiguity, two-word self-paced reading better simulates free-field reading during eye-tracking than one-word self-paced reading.

Why then did Ferreira and Clifton (1986) not find a suggestion of an interaction with animacy since some of their inanimate noun phrases were strongly constraining and some of their sentences contained agentive "by"-phrases? The likely explanation has to do with the particular set of materials. Many of the sentences with "by"-phrases had only weakly biasing nouns and many of the sentences with strongly biasing nouns had long prepositions, which would normally require a separate fixation to be recognized (see Burgess & Tanenhaus, 1992).

Maryellen MacDonald and Neal Pearlmutter (MacDonald, 1992; Pearlmutter & MacDonald, 1992) have presented a constellation of results with relative clauses that are similar to the results described here. For example, MacDonald (1992) manipulated several different kinds of constraining information, including animacy, verb subcategorization information, and "post-ambiguity" constraints associated with point of disambiguation. All three kinds of information independently decreased reading times for reduced relatives. When the constraints were combined, reduction effects were almost completely eliminated. The results indicate that the presence of information that correlates highly with the relative clause construction can be coordinated to constrain parsing decisions for this structural ambiguity.

Pearlmutter and MacDonald (1992) show that even weak semantic

1 Note that we are not claiming that self-paced reading with a two-word window is as natural as normal reading, or that it is *generally* preferable to one-word presentation.

constraints can affect the time course of ambiguity resolution with reduced relatives. In particular, ambiguity resolution is faster for animate noun phrases that are atypical agents for the following verb (e.g., The prisoner captured...). While these effects occur relatively late in the relative clause as measured by standard analysis of variance techniques, regression analyses show that the effects actually begin at, or shortly after, the ambiguous verb. A recent replication of these results conducted in our laboratory is reported in Tabossi et al. (1993).

In sum, semantic constraints that are relevant to argument assignment have clear and immediate effects on ambiguity resolution. However, the effects are restricted to conditions under which the relevant alternatives would both be active. This pattern of results is clearly consistent with the constraint-based framework.

While the set of results we have described are naturally accommodated by constraint-based models, they could be accounted for within a two-stage parsing framework in one of two ways. The first alternative would be to incorporate syntactically-relevant features such as animacy within the domain of the first-stage parser. However, this move cannot naturally accommodate the effects that are seen with animate noun phrases that are atypical agents. The second approach would be to argue that all of the effects observed in these studies are revision effects. On this view, the initial attachment stage is difficult to observe under conditions where potentially disambiguating information is available parafoveally because the attachment is extremely rapid and evaluation and revision begins almost immediately. We will return to this alternative in more detail in the general discussion.

DISCOURSE CONTEXT

Discourse-based models assume that a mental model of the events and entities being discussed in the discourse is continuously updated during sentence comprehension (e.g., Crain & Steedman, 1985; Marslen-Wilson & Tyler, 1987; Altmann & Steedman, 1988). Since many linguistic expressions can only be interpreted by making reference to information in the discourse model, it might be expected that the 'referential context' of these expressions could impose constraints on subsequent syntactic ambiguity resolution (Crain & Steedman, 1985; Altmann & Steedman, 1988). For example, consider what needs to be present in a discourse to make felicitous either a main clause interpretation or a relative clause interpretation of the following ambiguous fragment:

5. The student spotted...

If (5) is taken to be part of a main clause (e.g., "The student spotted the proctor and ..."), "The student" is an anaphoric noun phrase. Thus, there

needs to be at least one 'student' in the discourse context which this expression can refer to (i.e., there must be an antecedent that is in discourse focus). In addition, the verb "spotted" is a past tense verb which introduces a new event into the immediate discourse. As pointed out in Trueswell and Tanenhaus (1991, 1992), the introduction of a new past event requires the current discourse segment to have a temporal relation that is consistent with past events (i.e., other events in the discourse segment must also be in the past, otherwise a separate discourse segment that is consistent with past events must be established). Thus, even the past tense verb "spotted" has certain contextual dependencies which make presuppositions about the discourse.

If (5) is taken to be part of a relative clause (e.g., "The student spotted by the proctor was expelled."), the entire phrase is part of a complex anaphoric expression which refers to a discourse entity, i.e., a 'student', that is the passive participant of some 'spotting' event. Since the relative clause *modifies* the noun phrase "the student", it could be argued that a *set* of possible discourse referents (i.e., a set of students) needs to be in discourse focus, from which the relative clause expression distinguishes a single entity (i.e., the particular student that was involved in a spotting event). Moreover, the verb "spotted" as a participial verb in a relative clause refers directly to an event already in the discourse. Thus, the participial verb in a relative clause has different discourse presuppositions than a past tense verb in a main clause. The verb "spotted" in a relative clause requires a spotting event in discourse to which the verb can refer, and places no restrictions on the temporal properties of the current discourse segment (see Trueswell & Tanenhaus, 1991, 1992).

If referential context can be used by the parser, then there are at least two classes of discourse constraint that could prevent syntactic misanalysis in "The student spotted by the proctor...". The contextual dependencies of the verb (e.g., "spotted") would support a relative clause over a main clause interpretation when the current discourse segment has a temporal relation that makes the introduction of past events infelicitous. The contextual dependencies of the noun phrase (e.g., "The student") would support a relative clause over a main clause interpretation when the current discourse segment has a set of students in focus.

Temporal Context

Trueswell and Tanenhaus (1991, 1992) explored whether temporal discourse constraints influence the processing of relative clauses in studies using contexts such as those in (6).

6. a. Several students were sitting together taking an exam in a large lecture hall earlier today. A proctor noticed one of the students cheating.
   b. Several students will be sitting together taking an exam in a large lecture hall

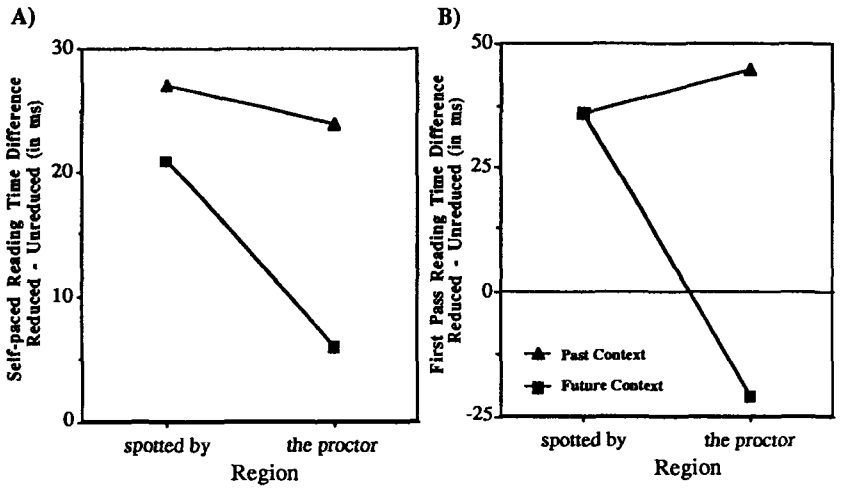

Fig. 1. (a) Two-word self-paced reading time differences (reduced minus unreduced) for past contexts and future contexts (from Trueswell & Tanenhaus, 1991). (b) First pass reading time differences (reduced minus unreduced) for past contexts and future contexts (from Trueswell & Tanenhaus, 1992).

later today. A proctor will notice one of the students cheating.
Target: The student (who was) spotted by the proctor will receive a warning.

A main clause interpretation of the fragment "The student spotted..." in the past context (6a) simply requires a new past event to be introduced into the current discourse segment. In contrast, a main clause interpretation in the future context (6b) requires considerable discourse modification, e.g., the establishment of a separate discourse segment with different temporal properties (see Trueswell & Tanenhaus, 1991, for examples). Therefore, a fragment like "The student spotted..." should be interpreted as part of a main clause in the past context and as part of a relative clause in the future context. This prediction was confirmed in a sentence completion study (Trueswell & Tanenhaus, 1992). Moreover, in two different two-word self-paced reading studies (Trueswell & Tanenhaus, 1991) and in a study monitoring eye movements (Trueswell & Tanenhaus, 1992), effects of relative clause reduction were decreased in the future contexts, suggesting that temporal context can influence structural commitments. Again, the results for self-paced reading with a two-word window and for eye-tracking were virtually identical, see Figure 1.

The only indication of difficulty with reduced relatives in future contexts came from small elevations found in the first half of the relative clause ("spotted by") in both self-paced reading and the first pass reading times of the eye movement study. In past contexts, longer reading times were observed

at the verb + "by" region and at the noun phrase within the prepositional phrase. In sum, these results show that temporal context rapidly influences ambiguity resolution.

Referential Noun Phrase Contexts

Most other work examining referential effects in sentence comprehension has focussed on whether the presence of a set of possible noun phrase referents induces a preference for a modifier structure. For instance, Crain (1980) compared grammaticality judgements to sentences in which the ambiguous phrase, such as "that he was arresting", was either part of a sentential complement (7a) or a relative clause noun phrase modifier (7b). Introducing a context that should require noun phrase modification (e.g., two criminals, only one of which is being arrested by the policeman) resulted in subjects judging the relative clause sentences (7b) to be more acceptable than the sentential complement sentences (7a). The opposite preference was found when the context supported the simple noun phrase analysis (e.g., one criminal).

7. a. The policeman told the criminal that he was arresting everybody in the room.
   b. The policeman told the criminal that he was arresting to lie down on the floor.

Recently, and more crucially, Altmann, Garnham, and Denis (1992) have found that these off-line biases appear to influence initial parsing commitments. In a set of experiments in which readers' eye-movements were monitored while they read relative clause/sentential complement ambiguities, Altmann et al. (1992) showed that a context with two noun phrase referents biased the reader toward the relative clause interpretation, as indicated by slower first pass fixation times and more regressive eye-movements in the sentential complement sentences. With large scoring regions, however, it is difficult to determine whether the effect of context is indeed immediate. Using a one-word self-paced reading paradigm, and sentences which are disambiguated earlier (e.g., "The headmaster told the boy that (he) had...") Mitchell, Corley, and Garnham (1992) found only late effects of referential context.

Effects similar to those of Altmann et al. (1992) were also found in an earlier study (Altmann & Steedman, 1988), which examined self-paced reading times to sentences containing prepositional phrase attachment ambiguities, like those in (8):

8. a. The burglar blew open the safe with the dynamite and ran off with the loot.
   b. The burglar blew open the safe with the new lock and ran off with the loot.

The point of syntactic ambiguity in these sentences occurs at the preposition

"with" and is not resolved until the noun "dynamite" or "new lock". The preposition can either attach to the verb as Instrument (8a) or it can attach to (and modify) the noun phrase "the safe" (8b). These constructions in isolation tend to be read with a preference for VP-attachment, thus causing a garden-path effect in the sentences that are more plausibly interpreted as NP-attached (Rayner et al., 1983; but cf. Taraban and McClelland, 1988). With contexts that contained two NP referents, (e.g., two safes, one with a new lock and one with an old lock), Altmann and Steedman (1988) reversed the result. Sentences which were more plausibly VP-attached elicited garden-paths (slowed reading of the PP).[2] This immediate effect of referential context on PP-attachment ambiguities has been replicated in self-paced reading experiments and in eye-tracking by Britt, Perfetti, Garrod and Rayner (1992); but see Ferreira and Clifton (1986).

In contrast, studies with reduced relative clauses have failed to find effects of referential context. Ferreira & Clifton (1986) tracked readers' eye-movements in reduced and unreduced relative clause sentences preceded by contexts containing one or two NP referents and found no immediate influence of context on the size of the reduction effect. Britt et al. (1992) also manipulated a form of focus/referential context with reduced relative clauses (i.e., the referent was backgrounded in discourse to make a complex NP reference more felicitous than a simple NP reference, and information was provided in the context that would support the content of a relative clause), and found that the biasing context did not decrease the reduction effect observed when the context did not support a relative clause. The only reading time study using reduced relatives that has found support for the traditional Referential Theory (e.g., Crain & Steedman, 1985) did not introduce a two NP referent context (Ni & Crain, 1990). Rather, the sentence was preceded by "Only" in order to bias the reader toward a complex NP interpretation because of the referential presupposition entailed by "only". Using word-by-word self-paced reading coupled with a grammaticality detection task, Ni and Crain (1990) found clear effects of "only" facilitating the reduced relative clause reading.

In sum, studies examining the effects of discourse constraints in on-line

2 In this conservative version of the Referential Theory, Altmann and Steedman (1988) may be drawing too narrow a picture of the context effect they observe. A close examination of their stimuli reveals that the contexts first set up the main character's plan, "He felt like smashing a window," and then provide two possible routes for completing that plan, "In front of him he saw a window made of stained glass and a window which had bars covering it." It is likely that such a context produces an expectation in the reader for discrimination between this minimal pair of windows: "Which window did he smash?" This expectation for resolution of a conceptual uncertainty, *regardless of referential considerations*, may cause the reader to prefer a complex NP analysis of "the window ..." in the target sentence (Spivey-Knowlton, 1992).

parsing have found somewhat mixed results. Although some studies have found clear discourse effects (Altmann & Steedman, 1988; Altmann et al., (1992); Britt et al., 1992; Ni & Crain, 1990; Trueswell & Tanenhaus, 1991, 1992), many others have failed to find such effects (Britt et al., 1992; Ferreira & Clifton, 1986; Mitchell et al., 1992). However, these differing results might be expected under a constraint-based perspective. Effects of discourse might only arise if (1) the contextual information is indeed highly constraining with respect to syntactic structure, and (2) local information makes sufficiently available the alternative forms of the ambiguity.

The present research examined the effects of noun phrase referential context on the processing of ambiguous reduced relative clauses. We explored whether referential contexts can influence parsing decisions under conditions in which: a) norms are used to establish that the contexts provide constraint at the point of ambiguity, and b) the mode of presentation (two-word format) facilitates the availability of the less frequent relative clause structure.

Experiment 1

This experiment examined reading times to relative clauses in contexts which either did or did not establish a unique referent for a noun phrase at the beginning of the reduced relative clause. Sentence (9a) begins with a definite noun phrase followed by a verb that is ambiguous between a simple past tense (main clause) or a participial form (reduced-relative clause):

9. a. The actress selected by the director believed that her performance was perfect.
   b. The actress who was selected by the director believed that her performance was perfect.

The definite NP, "the actress", presupposes a single actress in context. Interpreting "selected" as part of a main clause maintains this presupposition. However, interpreting "selected" as part of a relative clause makes it part of a complex NP ("the actress selected by..."). A complex definite NP, whether modified by a prepositional phrase or a relative clause, presupposes a *set of possible referents*, one of which is being referred to (cf. Heim, 1982). In a context that contains only one actress, the reader will not need a complex noun phrase to find a unique referent. Thus, upon encountering the ambiguous verb, the reader will opt for the main clause interpretation because it requires no revision of the mental model. However, in a context that contains two actresses, the reader should immediately opt for the reduced-relative interpretation because the *simple* NP interpretation of "the actress" does not have a unique referent.

Clifton and Ferreira (1989) have pointed out that relative clauses are frequently used for purposes other than selecting from an existing set of discourse entities. This is certainly true in the case of sentences outside of

context. Consider the following sentence, "The husband angered by his wife walked out of the house." This sentence does not necessarily presuppose a set of husbands in discourse. (Although, it may be that the unrestrictive reading prefers commas around the relative clause more so than the restrictive reading does.) This would suggest that Referential Theory may not adequately explain parsing biases in isolated sentences (see Spivey-Knowlton & Sedivy, 1992). However, when appropriate discourse contexts are involved, such as those that contain two potential referents for the definite NP, it would seem that the purpose of discriminating between discourse entities is a particularly salient use of relative clauses.

METHOD

Subjects

Thirty-six undergraduates from the University of Rochester participated in this reading time experiment for course credit. All were native English speakers and were naive to the experimental manipulations.

Materials and Design

Twenty-four target sentences were constructed in which the first definite NP was both a plausible agent and a plausible patient of the subsequent syntactically ambiguous verb. Before conducting the reading time study, these 24 sentences (reduced versions only; embedded among 36 filler sentences) were normed in a sentence completion study performed by 24 undergraduates of the University of Rochester. Each sentence fragment ("The actress selected") was preceded either by a 2-NP-Referent context, a 1-NP-Referent context, or no context at all; thus three versions of each stimulus formed three stimulus lists. In eight of these sentences, there did not appear to be a substantial difference in reduced relative completions between the 1-NP-Referent and 2-NP-Referent contexts. The remaining sixteen stimuli were slightly revised in an attempt to increase their context-dependence. A similar completion study was then performed by another 24 undergraduates on these 16 improved stimuli (among 44 fillers). As in all of the statistical analyses we will present, stimulus list and item group (for subject and item analyses, respectively) were included in the analyses of variance as between-subject factors to better account for variance in the error term. The results revealed a main effect of Context; $F1(2,42) = 20.4$, $MS_e = .0514$, $p < .001$; $F2(2,26) = 103.69$, $MS_e = .0069$, $p < .001$. The sentence fragments were completed as reduced relatives 1% of the time in the Null Context, 25% of the time in the 1-NP-Referent Context, and 43% of the time in the 2-NP-Referent Context. Planned comparisons showed that all three means were significantly different from one another (all $ps < .02$).

Although the differences between the one and two NP referent contexts are reliable, they are, in fact, quite small. Several factors may contribute to this.

TABLE 1

Context
a. In the visiting room, two prisoners began yelling at each other. To prevent a fight, the guard removed one of the prisoners from the room but not the other.
b. In the visiting room, a prisoner and a visitor began yelling at each other. To prevent a fight, the guard removed the prisoner from the room but not the visitor.
Target
a. The prisoner removed by the guard fought violently to break free of the guard's grip.
b. The prisoner who was removed by the guard fought violently to break free of the guard's grip.

First of all, the relatively high proportion of relative clauses in one NP referent contexts (25%) may have been due to the fact that many of the fragments did not have natural main clause completions in the one NP referent context. Since all of the test sentences for the reading time study continued as relative clauses and because the oddity of a main clause would depend upon relating the fragment to the context, this was not a problem for the reading time study. However, in the completion study, subjects may have tried to complete the fragment as a main clause and then shifted to a relative clause because the main clause continuation that they generated was odd given the context. The percentage of relative clauses in the two NP referent contexts may have been reduced because the verb that ended the fragment was used in the past tense form in the preceding sentence. This would tend to make the participial form less available (Trueswell & Tanenhaus, 1991). In fact, seven of the 24 subjects did not generate any relative clause completions.

The percentages of reduced relative completion in the three context conditions for each of these sentences can be seen in the Appendix. These 16 sentences were then used in the reading time study. Table 1 displays two versions of a context and two versions of a target sentence.

As addressed in Trueswell and Tanenhaus's (1991) work, there may be some bias introduced by using the same verb in the context (in active form) as that in the target sentence (in passive form). Much like Bock's (1986) evidence for syntactic form priming in production, Trueswell and Tanenhaus (1991) found that when the context contains the same verb in the context (in active form) as in the target sentence (in passive form), there is a greater tendency toward interpreting the target sentence as an active main clause than when the context used a synonymous verb. Thus, in this study, the referential context must overcome not only the frequency bias toward a main clause, but also a possible syntactic form priming bias *against* a passive interpretation of the verb in the target sentence.

The reading time experiment had a 2 × 2 design with Context (1 NP Referent / 2 NP Referents) and Reduction (Reduced Relative / Unreduced Relative) as the independent variables. Four of the 16 target sentences were assigned to each of the four experimental conditions, which were rotated to create four versions of each stimulus. Each subject was exposed to only one of the four stimulus lists, and therefore to only one version of any one experimental item. The 16 experimental stimuli were randomly embedded within 32 filler stimuli, with at least one filler stimulus intervening every two experimental stimuli. Of the 32 filler items, 18 began with an NP-verb sequence, and were thus temporarily ambiguous between main clause and reduced relative readings. Fifteen of these sentences were resolved as main clauses. All of the experimental stimuli and half of the filler stimuli were followed by yes/no questions that (for the experimental stimuli) revealed what syntactic commitment the subject had finally made. Subjects pressed the 'yes' or 'no' buttons to give their answers.

Procedure

Stimuli were presented on an IBM clone with a Digitry board and button box installed. Subjects pressed one button to begin a trial, at which time a row of dashes appeared on the screen. (A dash replaced each character in the sentence; while spaces and the period remained unchanged.) Subjects then pressed a different button to present each sentence of the context, and then each segment of two words in the target sentence, in a non-cumulative fashion (Just, Carpenter, & Woolley, 1982). Reading times were recorded for the first four two-word segments of the reduced relative target sentence and the first five two-word segments of the unreduced relative. Recording regions of the target sentences totaled less than 80 characters long, and fit on a single line on the monitor.

Subjects were instructed to read the sentences at a comfortable pace that closely approximated their normal reading speed, and to read carefully enough to correctly answer the questions. Including a practice session of ten trials, the entire experiment lasted approximately 25 minutes.

RESULTS

The reading times and differences for each of the recorded regions are presented in Table 2. All subjects answered at least 80% of the comprehension questions accurately. An analysis of variance was computed for the reading times collapsed across all recorded regions. In this analysis, a main effect of Reduction showed that the recorded regions of unreduced relatives (461ms) were read faster overall than those of reduced relatives (491ms); $F1(1,32) = 6.61$, $MS_e = 20309$, $p < .02$; $F2(1,12) = 4.62$, $MS_e = 12911$, $p = .053$.

A main effect of Context was also observed. When the context contained two NP referents (460ms), the target sentences were read faster than when the

TABLE 2
Reading Time (ms) by Sentence Region

	Det + noun	Verb + "by"	Det + noun	Main verb region
1 NP referent				
Reduced	612	462	494	509
Unreduced	*596*	*416*	*384*	*459*
Reduction Effect	16	46	110	50
2 NP referents				
Reduced	547	410	422	472
Unreduced	*572*	*403*	*410*	*443*
Reduction Effect	–25	7	12	29

context contained only one NP referent (492ms); $F1(1,32) = 8.16$, $MS_e = 17594$, $p < .01$; $F2(1,12) = 13.76$, $MS_e = 4632$, $p < .005$. This felicity effect was also obtained by Altmann and Steedman (1988). It is accountable by the fact that modifying a noun phrase which has already achieved successful reference is less felicitous than modifying one which has not.

An interaction between Context and Reduction was also observed; $F1(1,32) = 7.63$, $MS_e = 11507$, $p < .01$; $F2(1,12) = 5.66$, $MS_e = 6355$, $p < .05$. In the 1-NP-referent context, reading times were slower to the reduced relatives (519ms) than to the unreduced relatives (464ms), whereas in the 2-NP-referent context, there was no difference (463ms vs. 457ms, respectively).

Focussing on the immediate points of ambiguity and disambiguation, an analysis of variance was computed separately for reading times in the verb + "by" region and for the following noun phrase region. Determining whether Context interacts with Reduction in either of these two regions, which together make up the relative clause, allowed us to identify the locus of the context effect. For the verb + "by" region, a main effect (significant by items only) of Reduction was observed (see Table 2); $F1(1,32) = 3.33$, $MS_e = 7472$, $p = .077$; $F2(1,12) = 8.44$, $MS_e = 1222$, $p < .02$. A marginal main effect of Context was also observed in this region (see Table 2); $F1(1,32) = 3.87$, $MS_e = 9792$, $p = .058$; $F2(1,12) = 3.65$, $MS_e = 4165$, $p = .08$. The interaction of Context × Reduction was not statistically significant for the verb + "by" region; $F1(1,32) = 2.12$, $MS_e = 6190$; $F2(,12) = 3.2$, $MS_e = 1610$. However, simple effects analyses revealed that the Reduction difference was significant (by items) in the 1-NP-Referent Context [$F1(1,32) = 3.25$, $MS_e = 11407$, $p = .08$; $F2(1,12) = 7.76$, $MS_e = 1935$, $p < .02$], but not in the 2-NP-Referent Context [$F1$ and $F2 < 1.0$].

In the next region, the Context × Reduction interaction was significant; $F1(1,32) = 8.05$, $MS_e = 10760$, $p < .01$; $F2(1,12) = 5.87$, $MS_e = 6277$, $p < .05$.

Within the 1-NP-referent context, the noun phrase region of a reduced relative clause was read more slowly than that of an unreduced relative clause, whereas in the 2-NP-referent context, there was no difference. Again, simple effects showed a significant effect of Reduction in the 1-NP-Referent Context [$F1(1,32) = 15.27$, $MS_e = 14303$, $p < .001$; $F2(1,12) = 10.6$, $MS_e = 8808$, $p < .01$], but not in the 2-NP-Referent Context [$F1 < .5$; $F2 < .5$]. A main effect of Reduction, but not Context, persisted into this region also; $F1(1,32) = 13.62, MS_e = 9869, p < .005$; $F2(1,12) = 8.45, MS_e = 6831, p < .02$.

Table 2 shows, in the 2-NP-Referent Context, a slight rise in the Reduction difference as the sentence progresses. It is conceivable that statistically reliable slower processing at the fourth recorded region could be indicative of a delayed effect of Reduction, even in the 2-NP-Referent Context. To address this possibility, we analyzed reading times in this fourth region. However, both the analysis of variance and the simple effects analyses revealed no significant effects at this sentence region.

To analyze reading times for the relative clause as a whole, we collapsed across the verb + "by" and determiner + noun regions. Main effects of Context (by subjects only) [$F1(1,32) = 5.58$, $MS_e = 4860$, $p < .05$; $F2(1,12) = 3.22$, $MS_e = 3561$, $p < .1$] and of Reduction [$F1(1,32) = 10.38$, $MS_e = 6622$, $p < .005$, $F2(1,12) = 10.07$, $MS_e = 2901$, $p < .01$] were again observed. Most importantly, however, the interaction between Context and Reduction for the whole relative clause was robust; $F1(1,32) = 13.01$, $MS_e = 3210$, $p < .002$; $F2(1,12) = 9.44$, $MS_e = 1842$, $p < .02$. Once again, simple effects analyses revealed a reliable effect of Reduction (478ms vs. 400ms) in the 1-NP-Referent Context [$F1(1,32) = 15.15, MS_e = 7182, p < .001$; $F2(1,12) = 11.65$, $MS_e = 3933$, $p < .01$], and none (416ms vs. 407ms) in the 2-NP-Referent Context [$F1 < 1$; $F2 < 1$].

DISCUSSION

The results clearly demonstrated that referential context had immediate effects on ambiguity resolution for reduced relative clauses. Reduced relative clauses were more difficult than unreduced relatives in contexts that established a unique referent for a definite noun phrase at the beginning of the clause, whereas no reduction effect occurred when the context established two possible referents. Thus, the results confirm the predictions made by Referential Theory.

Nonetheless, there was a numerical difference between reduced and unreduced relative clauses that would be consistent with a small garden-path. However, there is another possible reason why unreduced relative clauses might be easier than reduced relative clauses. In an unreduced relative, the relative pronoun immediately establishes that the structure is a relative clause and allows the reader to begin to establish anaphoric links to the context. In a reduced relative clause, these processes cannot take place until the verb is

encountered. Thus, reduced relatives may be more difficult than unreduced relatives for reasons unrelated to ambiguity resolution (Trueswell et al., 1992; Tanenhaus, Carlson & Trueswell, 1989). Moreover, Ferreira and Henderson (1993) present evidence that readers speed up as they proceed through a sentence, and therefore, comparing reading times from reduced and unreduced relative clause sentences may overestimate the overall reduction effect. One way to control for these problems is to compare reduced relative clauses with morphologically ambiguous verbs to reduced relative clauses with verbs that are morphologically unambiguous because they use different forms for the past tense and participial.

Experiment 2

This experiment used the same contexts as were used in Experiment 1 with a matched set of morphologically ambiguous (e.g., removed) and morphologically unambiguous verbs (e.g., taken). For example, "The prisoner removed..." can be the beginning of a main clause or the beginning of a reduced relative clause, whereas "The prisoner taken..." can only be the beginning of a reduced relative clause.

METHOD

Subjects

Thirty-two undergraduates from the University of Rochester participated in this experiment for course credit. All were native English speakers and were naive to the experimental manipulations.

Materials and Design

The 16 experimental items and 32 filler items from the reading time study of Experiment 1 were used in this experiment with small, but important, changes. Instead of the target sentences having reduced or unreduced relative clauses, they had ambiguous or unambiguous reduced relative clauses. The unambiguous participial verb that replaced the ambiguous participial verb (to create the baseline condition) did so in both the target sentence and in the context; see Table 3. When the target sentence is (b), then the context will have "took" instead of "removed". When the target sentence is (a), the context will have "removed" instead of "took". The experimental design was, analogous to Experiment 1, a 2 × 2 factorial manipulation of Context (1-NP-referent, 2-NP-referents) and Ambiguity (Ambiguous past participle, Unambiguous past participle).

Procedure

The procedure was identical to that in Experiment 1. A practice session of ten trials preceded the experimental session of 48 trials. The experiment lasted approximately 25 minutes.

TABLE 3

Context
a. In the visiting room, two prisoners began yelling at each other. To prevent a fight, the guard removed/took one of the prisoners from the room but not the other.
b. In the visiting room, a prisoner and a visitor began yelling at each other. To prevent a fight, the guard removed/took the prisoner from the room but not the visitor.
Target
a. The prisoner removed by the guard fought violently to break free of the guard's grip.
b. The prisoner taken by the guard fought violently to break free of the guard's grip.

RESULTS

Reading times and differences for each recorded region are presented in Table 4. All subjects answered at least 80% of the comprehension questions accurately. An analysis of variance was first computed for the reading times collapsed across all recorded regions. The main effect of Ambiguity did not reach significance ($F1(1,28) < 1$; $F2(1,12) = 2.10$, $MS_e = 4735$), although the ambiguous sentences (562ms per region) were read somewhat more slowly than the unambiguous sentences (549ms per region). A main effect of Context was observed, such that recorded regions of sentences that followed 2-NP-referent contexts (534ms) were read more quickly than regions of sentences that followed 1-NP-referent contexts (577ms); $F1(1,28) = 11.28$, $MS_e = 21221$, $p < .005$; $F2(1,12) = 12.87$, $MS_e = 9299$, $p < .005$. The interaction between these two factors did not approach significance in this global analysis; $F(1,28) = 1.5$, $MS_e = 15400$; $F(1,12) = .69$, $MS_e = 16699$.

Additional analyses of variance were computed for individual regions. At the verb + "by" region, there was a main effect of Context in which subjects read the verb + "by" faster when the context contained 2 NP referents than when it contained only 1 NP referent (see Table 4); $F1(1,28) = 6.44$, $MS_e = 5593$, $p < .02$; $F2(1,12) = 4.79$, $MS_e = 3764$, $p < .05$. Again, no main effect of Ambiguity was observed. The interaction between Context and Ambiguity at the verb + "by" region was significant by subjects but not by items; $F1(1,28) = 5.32$, $MS_e = 3233$, $p < .05$; $F2(1,12) = 2.28$, $MS_e = 3768$, $p = .15$. Simple effects analyses revealed a marginal effect of Ambiguity in the 1-NP-Referent Context [$F1(1,28) = 3.34$, $MS_e = 5720$, $p < .1$; $F2(1,12) = 3.25$, $MS_e = 2946$, $p < .1$] but none at all in the 2-NP-Referent Context [$F1$ and $F2 < 1.0$].

At the following determiner + noun region, a similar main effect of Context was also observed; $F1(1,28) = 4.54$, $MS_e = 15416$, $p < .05$; $F2(1,12) = 4.64$,

TABLE 4
Reading Time (ms) by Sentence Region

	Det + noun	Verb + "by"	Det + noun	Main verb region
1 np referent				
Ambiguous	691	532	543	594
Unambiguous	702	498	488	568
Ambiguity Effect	−11	34	55	26
2 NP referents				
Ambiguous	660	476	468	529
Unambiguous	*635*	*487*	*470*	*545*
Ambiguity Effect	25	−11	−2	−16

$MS_e = 7540, p = .05$. However, the interaction between Context and Ambiguity was not statistically significant. Again, simple effects analyses showed a reliable effect of Ambiguity in the 1-NP-Referent Context [$F1(1,28) = 4.80$, $MS_e = 10178$, $p < .05$; $F2(1,12) = 4.99$, $MS_e = 4893$, $p < .05$] but not in the 2-NP-Referent Context [$F1$ and $F2 < 1.0$].

Another analysis of variance was computed collapsing across the entire relative clause (i.e., "selected by the director"). In addition to the main effect of Context [$F1(1,28) = 7.4$, $MS_e = 6971$, $p < .02$; $F2(1,12) = 13.52$, $MS_e = 1908$, $p < .005$] and a marginal effect of Ambiguity [$F1(1,28) = 3.13$, $MS_e = 3764$, $p = .09$; $F2(1,12) = 3.38$, $MS_e = 1745$, $p = .09$], the analysis of variance revealed an interaction between Context and Ambiguity (significant by subjects only) [$F1(1,28) = 5.23$, $MS_e = 4047$, $p < .05$; $F2(1,12) = 1.92$, $MS_e = 5521$, $p = .19$], such that the 1-NP-Referent Context exhibited an Ambiguity effect (538ms vs. 493ms) and the 2-NP-Referent Context did not (472ms vs. 479ms). Simple effects analyses confirmed this result with a significant effect of Ambiguity in the 1-NP-Referent Context [$F1(1,28) = 8.41$, $MS_e = 3838, p < .01$; $F2(1,12) = 5.18$, $MS_e = 3116, p < .05$] and no such effect in the 2-NP-Referent Context [$F1$ and $F2 < 1.0$].

It could be argued that the difference in mean string length between the ambiguous verbs (8 characters) and the unambiguous verbs (5.69 characters) makes the unambiguous condition a less than perfect control. However, there is no reason to expect this difference in string length to affect reading times in one context but not the other. That is, the difference in string length cannot account for the interaction between ambiguity and context. Nevertheless, to eliminate this factor, we conducted a regression analysis of string length to reading time on each subject's data at the verb + "by" region, and computed corresponding residuals. This adjusts reading times for string length differences (cf. Ferreira & Clifton, 1986; Trueswell & Tanenhaus, 1991). We then conducted an analysis of variance on the residuals for that region. The

results are similar to what was observed with unadjusted reading times at this region. The main effect of Context was present, but it is only marginal; $F1(1,28) = 3.54$, $MS_e = 6136$, $p = .07$; $F2(1,12) = 3.64$, $MS_e = 3365$, $p = .08$. There was no effect of Ambiguity at this region. The interaction between Context and Ambiguity, as with unadjusted reading times, was significant by subjects but not by items; $F1(1,28) = 8.30$, $MS_e = 3820$, $p < .01$; $F2(1,12) = 2.56$, $MS_e = 3196$, $p = .14$.

DISCUSSION

As in Experiment 1, referential context had clear effects on ambiguity resolution for reduced relative clauses that began with a definite noun phrase. When the context established a unique referent for the noun phrase, readers experienced difficulty processing an ambiguous reduced relative clause compared to an unambiguous reduced relative. However, when the context established two possible referents, no such difficulty was observed. In addition, the small, and non-significant, ambiguity effect that was seen in the two NP referent contexts of Experiment 1 was completely absent in this experiment. In sum, referential contexts have immediate on-line effects on ambiguity resolution under conditions where (1) the contexts have been demonstrated to establish constraint at the point of ambiguity and (2) a presentation mode is used that allows or imposes a segmentation of the stimuli that mimics that in normal reading and facilitates availability of syntactic alternatives.

Experiment 3

To further demonstrate the importance of the availability issue, the stimuli from Experiment 2 were used in a single-word-presentation self-paced reading format. When the ambiguous verb is presented *without* the short preposition following it, the relative availability of the two alternative verb forms (simple past tense and past participial) is highly skewed toward the far more common simple past tense. Under these conditions, the effects of context should be weaker and delayed.

METHOD

Subjects

Thirty-six undergraduates from the University of Rochester participated in this experiment for course credit. All were native English speakers and were naive to the experimental manipulations.

Materials and Design

The 16 experimental items and 32 filler items from Experiment 2 were used in this experiment. Instead of the target sentences being presented in two-word segments, they were presented in one-word segments. The rest of the display

characteristics were unchanged from Experiment 2. The experimental design was identical to Experiment 2, a 2 × 2 factorial manipulation of Context (1-NP-referent, 2-NP-referents) and Ambiguity (Ambiguous past participle, Unambiguous past participle).

Procedure

Aside from the one-word presentation mode, the procedure was identical to that in Experiment 2. A practice session of ten trials preceded the experimental session of 48 trials. The experiment lasted approximately 25 minutes.

RESULTS

All subjects answered at least 80% of the comprehension questions accurately. The reading times and differences for the first noun through the main verb are presented in Table 5, and the differences for reduced and unreduced relative clauses at each of these word positions are plotted in Figure 2. The pattern of data was clearly different for this experiment than for either Experiment 1 or Experiment 2. At the verb and the "by", there were small ambiguity effects that were numerically larger in the two NP referent contexts, whereas in the following regions, the ambiguity effects were numerically larger for sentences in the one NP referent contexts. However, the only effects that were reliable are main effects. An analysis of variance was first computed for the reading times collapsed across all recorded word positions, as done in the previous experiments. A main effect of Context was observed, such that recorded word positions of sentences that followed 2-NP-referent contexts (319ms) were read more quickly than word positions of sentences that followed 1-NP-referent contexts (339ms); $F1(1,32) = 15.9$, $MS_e = 5267$, $p < .001$; $F2(1,12) = 10.61$, $MS_e = 3508$, $p < .01$. A main effect of Ambiguity was also observed in this analysis. Subjects read word positions of the sentences containing Unambiguous reduced relative clauses (323ms) faster than those in sentences containing Ambiguous reduced relatives (335ms); $F1(1,32) = 5.27$, $MS_e = 5636$, $p < .05$; $F2(1,12) = 5.37$, $MS_e = 2460$, $p < .05$. The interaction between Context and Ambiguity did not approach significance; $F1$ and $F2 < 1$.

More fine-grained analyses of variance were then computed for individual word positions. At the noun preceding the verb, a main effect of Context, in which 2 NP referents facilitated reading time, was robust by subjects but marginal by items; $F1(1,32) = 10.27$, $MS_e = 857$, $p < .005$; $F2(1,12) = 3.14$, $MS_e = 1245$, $p = .1$. This result suggests an early felicity effect, such that, when the context contained 2 NP referents, subjects had a greater expectation for one of those entities to be further discussed in the subsequent sentence. This interpretation fits well into Spivey-Knowlton's (1992) conceptual expectation proposal. He suggested that the referential theory's explanation of these context effects is conflated by the fact that the contexts may set up conceptual expectations for disambiguation of the critical NP (via

TABLE 5
Reading Time (ms) by Word Position

	Noun	Verb	"by"	Det	Noun	Verb
1 NP referent						
Ambiguous	338	351	347	334	331	371
Unambiguous	333	338	345	318	305	352
Ambiguity Effect	5	13	2	16	26	19
2 NP referents						
Ambiguous	322	332	335	297	316	341
Unambiguous	317	311	323	292	308	333
Ambiguity Effect	5	21	12	5	8	8

post-modification) whether it be definite or indefinite (see Footnote 1). Thus, independent of referential pragmatics, there is a potential role for conceptual expectations in the effects of these 2-NP-referent contexts.

As in the other experiments, an interaction between Context and Ambiguity anywhere from the verb to the following noun would suggest that context was having an immediate effect on the syntactic decisions of the language processor. At the verb, there was a main effect of Context (felicity effect) in which subjects read that word position faster when the context contained 2 NP referents than when it contained only 1 NP referent (see Table 5); $F1(1,32) = 6.37$, $MS_e = 3191$, $p < .02$; $F2(1,12) = 6.03$, $MS_e = 1500$, $p < .05$. The main effect of Ambiguity was not significant; $F1(1,32) = 2.00$, $MS_e = 5227$; $F2(1,12) = 4.69$, $MS_e = 989$. Moreover, the interaction between Context and Ambiguity at the verb did not approach significance; $F1$ and $F2 < 1$.

At the word position that follows, the preposition "by", no significant effects were observed. Then, at the determiner, a robust main effect of Context reveals another felicity effect in which this word position was read faster when the context contained 2 NP referents than when the context contained 1 NP referent (see Table 5); $F1(1,32) = 9.58$, $MS_e = 3748$, $p < .005$; $F2(1,12) = 10.83$, $MS_e = 1473$, $p < .01$. However, neither the main effect of Ambiguity ($F1 = 1.07$; $F2 = 1.09$) nor the interaction ($F1$ and $F2 < 1$) approached significance.

A turn-around was observed at the next word position, the noun. The main effect of Context was no longer present ($F1 < 1$; $F2 < 1$), but the main effect of Ambiguity, in which Ambiguous reduced relatives produced longer reading times than Unambiguous reduced relatives was reliable; $F1(1,32) = 4.98$, $MS_e = 2058$, $p < .05$; $F2(1,12) = 6.57$, $MS_e = 694$, $p < .05$. As with the other word positions, the interaction between Context and Ambiguity did not approach significance; $F1$ and $F2 < 1$. Finally, the main verb position showed only a main effect of Context again, reliable by subjects but marginal by items;

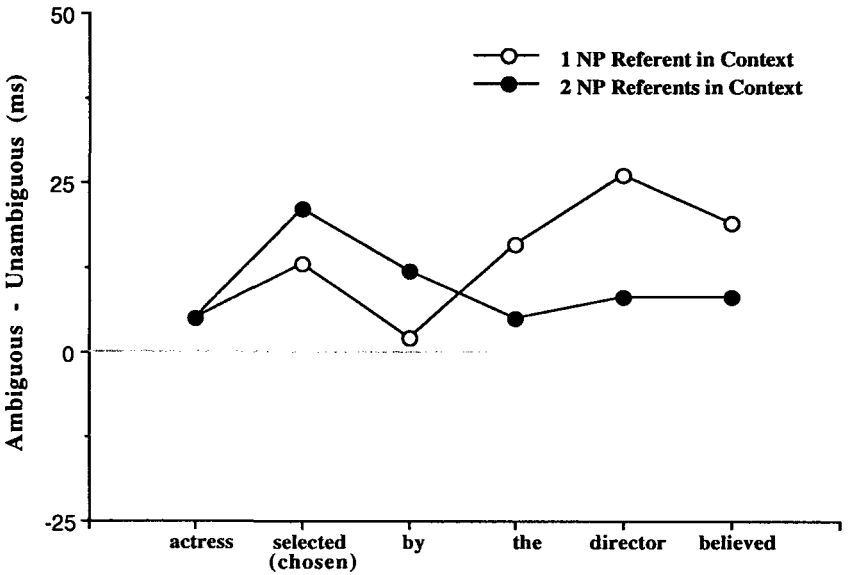

Fig. 2 Results of Experiment 3. Magnitude of the ambiguity effect in the two contexts as a function of word position.

$F1(1,32) = 5.86$, $MS_e = 3607$, $p < .05$; $F2(1,12) = 3.57$, $MS_e = 2630$, $p < .1$.

DISCUSSION

The only difference between this experiment and Experiment 2 was the mode of presentation. In Experiment 2, there was evidence for syntactic misanalysis in the one NP referent context but not in the two NP referent context. In contrast, the pattern of results was clearly different in the current experiment. Reading times were longer to ambiguous relative clauses in both contexts. Although context did not interact with ambiguity, the results across the word positions are suggestive. Early in the relative clause, the reduction effect was actually larger in the two NP referent context than in the one NP referent context, whereas the pattern reversed later in the clause. This pattern of results, which is similar to that reported by MacDonald (1992) and Pearlmutter and MacDonald (1992), is diagnostic of what happens when a contextual constraint supports the subordinate "reading" of an ambiguous word or phrase. These results are clearly parallel to the Burgess (1991) results with one-word presentation. As in the Burgess study, the present studies show that a contextual constraint that had clear and immediate effects with two-word presentation had weak and delayed effects with one-word presentation.

Clearly then, the effects of referential context depend upon the availability of the alternative readings of an ambiguity. Under conditions where both alternatives are likely to be available, context will have immediate effects,

whereas context will have weak and/or delayed effects when it attempts to bias a reading that is not reasonably predictable from the local input. This generalization provides an explanation for why the literature on referential context effects is currently somewhat equivocal. It seems likely that the degree of bias among alternative readings differs for different structures. In addition, it seems likely that the contexts used across studies differ in how strongly constraining they are at the point of the ambiguity.

DISCUSSION OF EXPERIMENTS 1-3

Several important conclusions emerge from these experiments. First of all, referential contexts have immediate effects on ambiguity resolution for reduced relative clauses, under conditions where the participial form is likely to become available quickly. This result demonstrates that (a) readers consult their discourse model when they encounter a definite noun phrase and (b) referential information from the discourse can be an immediate source of constraint in syntactic ambiguity resolution. Thus, two of the basic assumptions of the referential theory receive strong support.

Two-word Presentation

One might argue that the two-word presentation mode is unnatural. However, for the sentences that we used, the two-word presentation format grouped short function words with content words, thus corresponding to the pattern of eye-movements usually observed in reading, in which short function words are frequently skipped (Rayner & McConkie, 1976). More convincingly, as we discussed, several experiments have directly compared eye-tracking to self-paced reading with a two-word window for relative clause "by"-phrase constructions and found nearly identical results. Those eye-tracking experiments that have failed to find influences from referential context on reduced relatives did not consistently have short potentially-agentive prepositions, such as "by"[3], immediately following the verb (Britt et al., 1992, Experiment 3; Ferreira & Clifton, 1986, Experiment 2). Instead, they tended to have locative prepositional phrases (i.e., "The boy stood in the corner..."), particles following the verb (i.e., "The animal curled up in the basket..."), or even potential direct objects following the verb (i.e., "The woman delivered the letter..."). Each of these continuations is consistent with a main clause construction.

3 Note that viewing "by" with the ambiguous verb does not at that point resolve the ambiguity in favour of a participial verb form in a relative clause. It simply increases the availability of that alternative by virtue of the fact that "by" is frequently used to introduce agents in passive constructions, i.e. "The woman hired *by Fred* quit." But "by" can also be used in a *locative* or a *manner* role in a main clause continuation with an optionally intransitive verb, i.e., "The boy stood *by the telephone pole*" and "The dragon killed *by breathing fire on his prey*" (cf. Tabossi et al., 1993).

Theoretical and Methodological Implications

The interaction of context effect and presentation mode has both theoretical and methodological implications. Experiments using single-word self-paced reading may underestimate context effects when they separate an ambiguous word from potentially disambiguating information which would normally be processed parafoveally. Under these conditions, weak and/or delayed effects of context may be mistakenly attributed to the system being unable to make use of the context, when in fact, bottom-up processing has not made the relevant alternatives available quickly enough. From a theoretical perspective, the results highlight the importance of understanding the local factors that control availability – factors which have received far too little attention in the parsing literature. The fact that context effects depend upon local availability also suggests that purely discourse-based theories of syntactic ambiguity resolution are by themselves inadequate.

Finally, we should note that our context effects were obtained with contexts that were only weakly constraining. However, unlike most context studies in the literature, we used off-line norms to establish that our contexts were constraining at the point of the ambiguity.

General Discussion

Our results demonstrate clear effects of both local semantic context and discourse context on ambiguity resolution for relative clauses. When context provides strong syntactically relevant constraints in favour of a relative clause, and the alternatives are available, then both local semantic context and discourse context rapidly affect ambiguity resolution.

Let's briefly consider the implications of these results for current approaches to ambiguity resolution. First of all, the results of the experiments offer strong support for two of the fundamental claims made by discourse-based approaches, in particular, the referential theory. The first is that readers try to immediately link contextually dependent expressions to discourse representations. Clear evidence comes from the effects we reported for temporal and noun phrase referential contexts. Secondly, the constraints made available by the discourse are used in syntactic ambiguity resolution. However, we also discussed results demonstrating that a contextual factor unrelated to discourse, namely local semantic context, had clear effects on syntactic ambiguity resolution. In addition, under certain circumstances, referential contexts will have only weak or delayed effects because there is a strong local bias in favour of a particular reading. Neither of these effects are accounted for in the referential theory. In short, discourse-based factors are clearly important constraints that are used in parsing, but a purely discourse-based approach is inadequate.

The results are nicely accommodated by recent versions of constraint-based approaches to parsing in which the bottom-up input determines the set of

possible alternatives (e.g., MacDonald, 1992; Tabossi et al., 1993; Trueswell et al., 1992). For example, in MacDonald's model, alternatives will be partially activated depending on how likely they are given the input. Syntactically relevant contextual constraints can then provide evidence for or against competing alternatives. While these models need to be made more precise in order to generate quantitative predictions, they clearly predict an interaction between strength of contextual constraint and bottom-up availability of the alternatives. A brief scan of the literature supports this prediction. Where frequency of use is highly skewed toward one of the alternatives, as in reduced relatives (cf. Tabossi et al., 1993), on-line effects of context have been elusive (Britt et al., 1992; Ferreira & Clifton, 1986; Rayner et al., 1983; but see Ni & Crain, 1990). In contrast, for syntactic ambiguities in which the intrinsic availability of alternatives is less skewed, as in PP-attachment ambiguities (cf. Hindle & Rooth, 1990 and Spivey-Knowlton & Sedivy, 1992), on-line effects of context are more common (Altmann & Steedman, 1988; Britt et al., 1992; Spivey-Knowlton, 1992; but see Ferreira & Clifton, 1986 and Rayner et al., 1983).

We should note that this class of constraint-based approach does not predict that *all* of the information in a context will have immediate effects on parsing. First of all, local syntactic information will define the set of possible alternatives, much like the initial segments of a word will partially activate features of words belonging to a "cohort" (Marslen-Wilson, 1987; Norris, 1990). Secondly, the only information from the context that will have effects will be information that is both currently active and syntactically relevant. The two general types of contextual information that we explored in this article meet both of these conditions.

The constraint-based approach that we have outlined contrasts with the two-stage approach, adopted by restricted-domain models such as the garden-path theory, in which ambiguity resolution begins with a single analysis developed by a first-stage parser. Although the context effects just presented here are problematic for a two-stage approach, such an approach could accommodate these effects by treating them as part of the revision stage. This would require having a very small temporal window for the autonomous attachment stage, and it would require treating the revision process as constraint-based. However, the motivation for an autonomous first stage becomes less compelling as the temporal window shrinks and as the range of information that can have immediate, or nearly immediate, effects on ambiguity resolution increases (MacDonald, 1992; Trueswell, Tanenhaus, & Kello, in press). In the end, however, the issue will only be resolved when we have more detailed information about the time course of the resolution process and models (of both constraint-based and two-stage theories) that are precise enough to generate quantitative predictions.

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Appendix

The following are the contexts and target sentences used the experiments. For stimulus 1, the 2-NP-Referent Context is presented in brackets. For the remaining stimuli, only the 1-NP-Referent Context is shown. The 2-NP-Referent Contexts can be easily induced by analogy with stimulus 1. Following the segmented ("/") target sentence ("who was" is for Experiment 1 only), the percentage of reduced relative clause completions is given for the three context conditions in the norming study. Recall that Experiment 3 used one-word presentation format. Finally, the unambiguous participial verbs (from Experiments 2 and 3) are shown in parentheses with the ambiguous verb that they replace.

1. [Two patients were waiting for their doctor to introduce them to the team of specialists that would handle their case. The doctor presented one of the patients to them but not the other.] A patient and her son were waiting for their doctor to introduce them to the team of specialists that would handle their case. The doctor presented the patient to them but not the son. The patient / (who was) / presented by / the doctor / felt embarrassed / for getting / all the / attention. Null: 0, 1-NPR: .125, 2-NPR: .25 (presented/shown)

2. A knight and his squire were attacking a dragon. With its breath of fire, the dragon killed the knight but not the squire. The knight / (who was) / killed by / the dragon / fell to / the ground / with a / thud. Null: 0, 1-NPR: .375, 2-NPR: .125 (killed/slain)

3. A woman and a man wearing overcoats walked into a bank. The bank guard watched the woman but not the man. The woman / (who was) / watched by / the

guard / realized that / she was / no longer / inconspicuous. Null: 0, 1-NPR: 0, 2-NPR: .125 (watched/seen)

4. A mother took her son and daughter shopping with her at the market. When she left, she abandoned her son who was still in the toy aisle but not her daughter. The son / (who was) / abandoned by / his mother / continued to / play with / the toys. Null: .125, 1-NPR: .5, 2-NPR: .375 (abandoned/forgotten)

5. In the visiting room, a prisoner and a visitor began yelling at each other. To prevent a fight, the guard removed the prisoner from the room but not the visitor. The prisoner / (who was) / removed by / the guard / fought violently / to break / free of / the guard's / grip. Null: 0, 1-NPR: .375, 2-NPR: .375 (removed/taken)

6. The old lady was very abusive to certain members of her family. She constantly battered her daughter but not her son. The daughter / (who was) / battered by / her mother / thought that / she deserved / the punishment. Null: 0, 1-NPR: .125, 2-NPR: .25 (battered/beaten)

7. The likely suspect and his accomplice in the crime were placed in a line-up of several other men. The victim identified the suspect but not the accomplice. The suspect / (who was) / identified by / the victim / claimed that / he was / innocent. Null: .125, 1-NPR: .375, 2-NPR: .75 (identified/chosen)

8. One night a thief was checking out the neighboring homes of a family and a bachelor. He robbed the family but not the bachelor. The family / (who was) / robbed by / the thief / called the / police as / soon as / they realized / what had / happened. Null: 0, 1-NPR: .375, 2-NPR: .75 (robbed/woken)

9. A college admissions council was considering the applications of a student and a blue collar worker. They admitted the student but not the blue collar worker. The student / (who was) / admitted by / the council / suggested to / his friends / that they / apply to / the same / college. Null: 0, 1-NPR: .375, 2-NPR: .625 (admitted/taken)

10. A boy and a girl were fighting in their bedroom when their father walked in. He punished the boy but not the girl. The boy / (who was) / punished by / his father / began to / cry and / ran to / his mother. Null: 0, 1-NPR: .375, 2-NPR: .625 (punished/beaten)

11. An actress and the producer's niece were auditioning for a play. The director selected the actress but the not the niece. The actress / (who was) / selected by / the director / believed that / her performance / was perfect. Null: 0, 1-NPR: .375, 2-NPR: .625 (selected/chosen)

12. An actor and an actress were rehearsing on stage with the curtain half-closed. The curtain covered the actor but not the actress. The actor / (who was) / covered by / the curtain / complained about / the incident / for weeks. Null: 0, 1-NPR: .375, 2-NPR: .625 (covered/hidden)

13. A senator and a lawyer were debating on TV about international law. The next day, a news reporter criticized the senator but not the lawyer. The senator / (who was) / criticized by / the reporter / called the / TV station / and complained / about the / injustice. Null: 0, 1-NPR: .125, 2-NPR: .5 (criticized/shown)

14. A guide and a cameraman got stuck in a narrow crevice while traveling with a research team in the Arctic. The team had to abandon the guide but not the cameraman. The guide / (who was) / abandoned by / the team / died before / they could / contact help. Null: 0, 1-NPR: .25, 2-NPR: .25 (abandoned/forsaken)

15. A boy and a girl were smoking behind the school gym when the principal came walking toward them. He recognized the boy but not the girl. The boy / (who was) / recognized by / the principal / received a / two-day suspension. Null: 0, 1-NPR: 0, 2-NPR: .25 (recognized/known)

16. A boy was conducting an experiment on a rabbit and a hamster. He raised the rabbit himself but not the hamster. The rabbit / (that was) / raised by / the boy / responded to / him with / affection. Null: 0, 1-NPR: .125, 2-NPR: .5 (raised/grown)