

## Tense, Temporal Context and Syntactic Ambiguity Resolution

John C. Trueswell and Michael K. Tanenhaus

*Department of Psychology, University of Rochester, Rochester, New York, U.S.A.*

During sentence comprehension, events denoted by verbs must be related to other events already established in the discourse. This often requires the tense of a verb to be evaluated in relation to specific temporal properties of the discourse. We investigated the time course of this process by examining whether the usual bias to initially interpret a participial verb in a reduced relative clause as a past-tense verb in a main clause would be reduced or eliminated when the temporal properties of the discourse are inconsistent with a past-tense interpretation. In Experiment 1, the subjects completed fragments such as *The student spotted* when they appeared in contexts containing events occurring in the future or events occurring in the past. The fragments were typically completed as main clauses (e.g. *The student spotted - the proctor . . .*) in the past contexts, and as relative clauses (e.g. *The student spotted - by the proctor . . .*) in the future contexts. In Experiments 2 and 3, the subjects read target sentences presented two words at a time using a moving window paradigm. The target sentences began with relative clauses which were presented in past or future contexts. Reduced relative clauses were read faster in the future contexts as compared with the past contexts, indicating that the temporal information in the discourse reduced the garden path normally associated with this structure. The results demonstrate that temporal information from the discourse is accessed rapidly enough to be used in syntactic ambiguity resolution, indicating that the tense of a verb is immediately evaluated in relation to the discourse model. These results are interpreted as support for incrementalist approaches to comprehension in which a discourse model is continuously updated during comprehension and in which sentence processing is sensitive to the resulting constraints.

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Requests for reprints should be addressed to John C. Trueswell, Department of Psychology, Meliora Hall, University of Rochester, Rochester, New York 14627, U.S.A.

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## INTRODUCTION

Recent incremental approaches to sentence comprehension assume that a mental model of the events and entities being discussed in a discourse (e.g. Garnham, 1981; Johnson-Laird, 1983; Webber, 1979) is continuously updated during sentence processing (Altmann & Steedman, 1988; Marslen-Wilson & Tyler, 1987). Moreover, these approaches assume that sentence processing is sensitive to constraints provided by the discourse which are motivated by the incremental hypothesis. Some of the clearest evidence in support of these assumptions comes from recent studies that have demonstrated that the referential context for a definite noun phrase is rapidly used in syntactic ambiguity resolution (Altmann & Steedman, 1988; Crain & Steedman, 1985; Ni & Crain, 1990). These studies demonstrate that (a) readers immediately attempt to establish referential links between definite noun phrases and the prior discourse and (b) that sentence processing is sensitive to constraints provided by the referential context. In this article, we report results from a complementary line of research that examines the time course with which events in a sentence are related to those events already established in the discourse. We examined whether constraints established by the discourse context that are relevant to establishing the temporal order of events in the discourse also influence syntactic ambiguity resolution. More specifically, we examined whether the temporary garden path that readers usually experience when reading reduced relative clauses (e.g. *The student spotted by the proctor . . .*) would be reduced or eliminated when the temporal structure of the preceding discourse was biased against the normally favoured past-tense interpretation of the verb.

In order to motivate our experiments, it will be helpful first to illustrate how the interpretation of tense is contextually dependent in much the same way as is the interpretation of a pronoun or a definite noun phrase. In fact, Webber (1988) has recently argued that tense, by definition, should be considered a discourse anaphor. Following Webber (1979, 1988), a linguistic expression can be considered to be a discourse anaphor if (1) it refers to some discourse entity that has already been established by a linguistic expression or (2) it creates a new discourse entity that is "dependent" upon some other discourse entity. An example of the first case is illustrated in the sentence:

1. John picked up the ball and hit it.

The pronoun "it" meets the first defining condition for an anaphor because it refers to the discourse entity created by "the ball". An example of a dependent anaphor, modified from Webber (1979), is illustrated by:

2. When the bus came around the corner, I signalled to the driver to stop.

The definite noun phrase "the driver" makes use of the discourse entity associated with "the bus" to create a new discourse entity, namely "the driver of the bus" (Webber, 1979). This it is considered to be an anaphor according to Webber's second criterion.

A number of researchers have pointed out that the tense of a verb can only be interpreted in relation to the temporal information associated with the event structure of the discourse (Dowty, 1986; Hinrichs, 1986; Partee, 1984; Steedman, 1982; Webber, 1988). It is this contextual dependency that underlies the anaphoric properties of tense.<sup>1</sup> We will make the standard assumption that a discourse model includes a representation of the events in a discourse and the temporal relations among those events. As the discourse develops, old events are referred to and new events are introduced. New events are typically introduced by a verb in a main clause. The tense of the verb helps establish the temporal relations between the new event and the other events in the discourse. However, the information provided by tense alone is insufficient. Tense must be used in conjunction with the event structure of the discourse. Thus, tense is an anaphor according to Webber's second criterion; it assists in establishing a new event that is dependent upon the temporal properties of other events already established in the discourse model (Webber, 1988).

In order to see this, we need to introduce some basic information about the English tense system. Most current models of tense take as their starting point the work of Hans Reichenbach, who developed a model of the underlying semantic structure of the English tense system. Reichenbach (1947) proposed that the interpretation of tense requires three separate semantic entities:

- time of speech (*S*);
- time of event (*E*); and
- time of reference (*R*).

The time of speech, *S*, is the time at which the utterance occurs (usually thought of as "now"). The time of event, *E*, is the time at which an event (usually denoted by a verb) takes place. The time of reference, *R*,

<sup>1</sup>Although specific proposals differ on whether tense should be explicitly defined and treated as an anaphoric expression (Partee, 1984), there is general agreement that tense has contextually dependent properties that require analysis in relation to the temporal parameters of the discourse (Dowty, 1986; Hinrichs, 1986; Partee, 1984; Steedman, 1982; Webber, 1988).

represents the temporal perspective from which the described event is viewed.

When these ideas are incorporated into a model of discourse,  $S$  and  $R$  are typically considered variables which change during the progression of the discourse. When information from a new sentence is introduced into the discourse, the time of the event,  $E$ , associated with the verb of that sentence is determined using the tense of the verb and the current values of  $R$  and  $S$ . It is obvious how time of speech,  $S$ , changes as the discourse progresses, but it is less clear how the time of reference,  $R$ , is changed, or, for that matter, how it is first established. Dowty (1986) and others propose that the  $R$  of each sentence in a narrative is interpreted to be a time consistent with a definite time adverbial (e.g. *yesterday, tomorrow . . .*). If a time adverbial is not present in the sentence,  $R$  becomes a time which immediately follows the  $R$  of the previous sentence. While the details of various models differ,<sup>2</sup> most use tense to establish a time of the event,  $E$ , that is *dependent* upon the current values of the discourse parameters  $S$  and  $R$  (see Hinrichs, 1986; Steedman, 1982).

Each tense requires different configurations of  $E$ ,  $R$  and  $S$ . We will assume here that when a tense-marked verb appears in a "null-context", i.e. in isolation or at the beginning of a text, these configuration requirements are used to make assumptions about the temporal parameters of the discourse as a whole. Consider the following tensed verbs and the relationships they establish (" $<$ " denotes "preceding", " $>$ " denotes "following" and " $=$ " is "at the same time"):

3. *Bill mailed Susan a letter.* (simple past)  $E = R < S$
4. *Bill will mail Susan a letter.* (simple future)  $S < E = R$
5. *Bill had mailed Susan a letter.* (past perfect)  $E < R < S$

Consider now the following simplified example which demonstrates one way in which tense can be interpreted in relation to the current temporal discourse information.

- 6a. John *went* to the hospital. ( $E_1$ )
- b. He *had twisted* his ankle on a patch of ice. ( $E_2$ )

In sentence (6b), the reader can use the tense of the verb (past perfect) to determine that the event denoted in (6b) occurred before the event denoted in (6a). Using the temporal parameter terminology, the past tense in sentence (6a) establishes a time of reference,  $R$ , that is prior to the time

of speech,  $S$ . Then, the past perfect tense in (6b) is evaluated in relation to the current value of  $R$  (established in 6a) to determine the time of the event ( $E_2 < R = E_1$ ). Examples like this illustrate how readers can use tense in conjunction with the temporal information in the discourse to determine the basic temporal relationship between events.

More interesting examples of how tense interacts with a discourse model arise when there is a tense shift which requires a non-trivial change in the discourse structure. This can occur when the tense of a main clause verb places restrictions on  $R$  and  $S$  that are inconsistent with the current relationship established by the discourse, as in example (7):

- 7a. Tomorrow, Ms Brown will announce that she is running for President.
- b. She ran for President in the last election as well.

In this example, the first sentence establishes the beginning of a discourse segment, which contains an event occurring in the future, thus establishing an  $R$  and  $S$  configuration in which the time of reference follows time of speech ( $S < R$ ). The second sentence introduces a main clause in the past tense, which requires the opposite  $R$  and  $S$  configuration ( $R < S$ ). This sentence is felicitous only because temporal expression *in the last election* establishes a new discourse segment that has a time of reference preceding the time of speech. Without the adverbial phrase, the discourse is infelicitous, as is illustrated in (8):

- 8a. Tomorrow, Ms Brown will announce that she is running for President.
- b. She ran for President.

However, it should be pointed out that the tense of verbs in other types of clauses, such as relative clauses, seems to behave quite differently, with respect to the discourse, than does the tense of verbs in main clauses. The relative clause that appears in example (9a), i.e. *the man who gave the speech*, is part of a complex definite noun phrase expression which specifies a discourse object that is an active participant of some event already established in the discourse (e.g. some man who is the Agent of some "giving a speech" event). Presumably, the reader must infer such an event if one is not already present in the discourse. Thus, a verb in a restrictive relative clause typically does not establish a new event. Rather, it refers back to an event already established in the discourse. The tense of the verb, in conjunction with the current  $R$  and  $S$  values of the discourse, indicates the  $E$  value of the event being referred to.

Therefore, unlike a main clause with a past tense, a relative clause does not place restrictions on the temporal relationship between the time of reference and the time of speech in the discourse. This can be seen more

<sup>2</sup>For example, others propose that time of reference may also change based on general world knowledge about events, such as causal relations and the basic knowledge of the ontology of events (Moens & Steedman, 1988; Webber, 1988).

clearly in examples such as (9), in which the reader can easily imagine appropriate contexts for each of the relative clauses:

- 9a. Tomorrow, Bill will meet the man who gave the speech.
- b. Tomorrow, Bill will meet the man who will give the speech.
- c. Yesterday, Bill met the man who gave the speech.
- d. Yesterday, Bill met the man who will give the speech.

Thus, one would expect that the tense of a relative clause would only become unacceptable if there is no antecedent event that has an appropriate time of event associated with it, as in sentence (c) in the context of example (10):

- 10a. Two famous men visited our campus last week.
  - b. One gave a speech on the quad and the other had a private visit with the Dean.
  - c. \*Yesterday, my friend Bill met the man who will give the speech.
  - d. Yesterday, my friend Bill met the man who gave the speech.

As should be expected, the preference of (10d) over (10c) reverses if (10a) and (10b) are placed in the future tense (e.g. "next week" instead of "last week").

The preceding discussion has illustrated that the interpretation of the tense associated with a verb depends upon temporal information provided by the context, as well as the type of clause in which the verb appears. A natural question that arises from a processing perspective is, at what point in processing does the listener or reader consider tense in relation to the temporal properties of the discourse. Because the temporal relations among events is an integral part of a discourse model, the incremental perspective would predict that a reader would try to update the model immediately upon encountering a tensed verb in a main clause. In order to test this hypothesis, we made use of the well-known temporary ambiguity associated with reduced object-relative clauses. These structures are typically ambiguous because most English verbs use the same morphological form to mark the past tense and the participial forms. This results in a temporary structural ambiguity between a main clause and a relative clause. Thus, ambiguous fragments such as *The student spotted . . .* can be continued either as a main clause with a past-tense verb (e.g. *The student spotted the proctor and went back to work*) or as a relative clause with a participial verb (e.g. *The student spotted by the proctor was expelled*). Crucially, the past tense in a main clause and the participial form in a relative clause require different temporal and event information to be present in the discourse model and have different effects on the structure of the discourse. To illustrate this, consider both possible interpretations (main clause or reduced relative clause) of the fragment in contexts which

occur either in the future or in the past, as shown in (11) and (12) respectively:

11. Several students will be sitting together taking an exam tomorrow. A proctor will come up and notice one of the student's cheating. The student spotted . . .
12. Several students were sitting together taking an exam yesterday. A proctor came up and noticed one of the students cheating. The student spotted . . .

The main clause and relative clause interpretations of the ambiguous fragment *The student spotted* interact with the discourse in different ways. If the fragment is a main clause containing a past-tense verb, *The student* is an anaphoric noun phrase. The verb *spotted* introduces a new event into the discourse making use of the tense of the verb and the current temporal parameters *R* and *S*. For a past-tense verb, the time of reference, *R*, must precede the time of speech, *S*. These conditions are met in the past contexts. In the future contexts, however, the time of reference follows the time of speech. As we have seen in example (10), a past event cannot be felicitously embedded into the discourse without creating a new discourse segment with different temporal relations.

If, however, the ambiguous phrase *The student spotted* in (11) or (12) is interpreted as a relative clause with a participial verb, as in *The student spotted by the proctor*, the entire phrase is a complex anaphoric expression which specifies a discourse object that is a passive participant of some event (e.g. *some student who was the object of some "spotting" event*). Again, because a relative clause of this type refers back to some antecedent event, the tense of a verb in the relative clause does not place restrictions on the current values of *R* and *S*, but rather it places restrictions on when in time the antecedent event of the clause may occur.

However, even though the antecedent event (the "spotting" event) occurs in the future in context (11) and in the past in context (12), the relative clause *The student spotted by the proctor* is acceptable in both. This is because reduced object-relative clauses are in fact ambiguous with respect to tense. Without any context, *The student spotted by the proctor* could easily be: *The student who was spotted by the proctor*, or *The student who is spotted by the proctor*, or *The student who will be spotted by the proctor*, or *The student who will have been spotted by the proctor*, etc.

We first investigated whether temporal context can be used in syntactic ambiguity resolution by determining whether there is a bias to interpret a fragment such as *The student spotted* as a main clause in a context occurring in the past and as a relative clause in a context occurring in the future. This result is expected if we combine the basic incrementalist assumption with the assumption that readers have a bias against establishing either a new

discourse segment or a new time of reference unless it is explicitly marked in the discourse. As Webber (1988) points out, this "inertial" assumption is similar in spirit to the minimal inference assumption that is central to the referential theory of garden-pathing, in which readers and listeners make the minimal assumptions or presuppositions necessary to establish a referential link between a noun phrase and the discourse model (Altmann & Steedman, 1988; Crain & Steedman, 1985; Ni & Crain, 1990).

The incremental and the minimal inference assumptions combine to predict that the past-tense form of the verb in ambiguous fragments like *The student spotted* will be less preferred in future contexts like (11) because of the more complex discourse consequences associated with it. In the future context, the establishment of a new past event would require a new discourse segment and a new time of reference. A relative clause, on the other hand, would simply require an anaphoric link to the event entity already established in the previous sentence. In past contexts like (12), however, the past-tense form should be preferred because the introduction of a new past event does not affect the segmentation of the discourse or the basic relationships between the temporal parameters *R* and *S*. The only assumption in this case would be that determining the event referent, as associated with a verb in a relative clause, is more difficult and less preferred than introducing a new past event as associated with a main clause. In Experiment 1, we tested and confirmed these predictions in a sentence completion study. In Experiments 2 and 3, we used a self-paced reading task to provide a more on-line response measure.

## EXPERIMENT 1

In this experiment, the subjects were asked to complete ambiguous sentence fragments such as *The student spotted*, which were preceded by contexts similar to those illustrated in (11) and (12). The context typically introduced a set of discourse entities (*several students*) and then introduced a new event in which one of the entities was a passive participant (*A proctor noticed one of the students . . .*). This entity was the NP in the sentence fragment. The context either appeared in the past tense or in the future tense. In addition, the sentence fragment either began with a definite noun phrase (e.g. *The student spotted . . .*) or the quantifier "only" (e.g. *Only the student spotted . . .*).

The "only" manipulation was included to test a prediction about how the referential theory of garden paths would interact with discourse focus. The referential theory predicts that readers will interpret ambiguous fragments such as *The student spotted* as main clauses because the reduced relative interpretation requires more complex presuppositions. For the main clause, the reader needs only to introduce a new entity and new event into

the discourse model. In contrast, the reduced relative is most felicitous when there is a set of two or more entities that could be referred to by the NP and the particular referent of the NP can be distinguished from the others by some event which the referent participated in. In the absence of context, this information needs to be introduced into the discourse model.

In the discourse contexts that we created, the first sentence introduces a set of entities that includes the NP in the sentence fragment. The second sentence introduces a proposition that distinguishes the discourse entity referred to by the NP from the set. Thus the appropriate conditions for a relative clause interpretation are met except that the set introduced in the first sentence is no longer in focus (e.g. one could not felicitously refer to the set with a pronoun). Thus, the reader should be able to establish a referential link between the NP in the sentence fragment and the NP in the previous sentence, resulting in a main clause preference. However, the quantifier "only" explicitly forces a comparison to a set. This should lead the reader to bring the information from the prior sentence back into focus, thus establishing the appropriate discourse conditions for a relative clause interpretation. Thus, we predict that subjects would complete the fragments with "only" as relative clauses even in the past-tense contexts.

## Method

*Subjects.* A total of 40 undergraduates from the University of Rochester participated in the experiment for course credit. All of the subjects were native speakers of English.

*Materials.* Twenty sets of materials were developed for the experiment. Each set contained a short passage followed by a sentence fragment. The sentence fragment consisted of a definite noun phrase followed by a verb that was ambiguous between a past-tense and a participial form. A sample set is presented in Table 1.

The passages all had the following characteristics. The first sentence introduced a set of discourse entities (e.g. *Several students*), all of whom were participating in the same event (*taking an exam*). The second sentence differentiated one of the members from the rest of the set by making it a passive participant (either the theme or the patient) of an event (*The proctor noticed one of the students cheating*). We avoided using passive structures in order not to introduce a bias in favour of the participial form. Two additional criteria were used in selecting the verbs in the sentence fragment. The verb had to be similar in meaning to the main verb in the preceding sentence (the verb that introduced the event in which the noun phrase was the patient or theme) and thus it could be used to refer to that event in a reduced relative clause. The verb also had to allow a plausible

TABLE 1  
An Example of the Materials for Experiment 1

Example	
Past context	<i>Several students were sitting together taking an exam yesterday. A proctor came up and noticed one of the students cheating.</i>
Future context	<i>Several students will be sitting together taking an exam tomorrow. A proctor will come up and notice one of the students cheating.</i>
Definite NP fragment	<i>The student spotted . . .</i>
"Only" fragment	<i>Only the student spotted . . .</i>

past-tense continuation with the noun phrase as the agent, e.g. *The student spotted the proctor and knew he was in trouble.*

Two versions of the context passage and two versions of the fragment were constructed. A past- and future-tense version of each passage was written. In addition to the obvious tense changes, it was often necessary to introduce other minor changes, e.g. changing *yesterday* to *tomorrow*. The sentence fragment either began with a definite noun phrase or with the quantifier "only".

The 20 experimental trials were randomly embedded in each list with 30 distractor trials. The distractor passages used a variety of tenses and various syntactic forms were used in the sentence fragments. The design was fully crossed. Each subject saw each target passage once in either a past-tense or future-tense context with a sentence fragment beginning with either the definite noun phrase or beginning with the quantifier "only".

*Procedure.* The stimuli were presented on a personal computer equipped with a colour monitor. At the beginning of each trial the entire text, including the sentence fragment, was presented on the screen. The subjects were instructed to read the passage silently and then complete the sentence fragment as quickly as possible by making a grammatical sentence that made sense in the context. The subjects entered their completions on the keyboard.

## Results

The completions were scored by hand. All ungrammatical completions (less than 2%) were discarded. All other completions fell into two categories: past-tense main clause completions or participial relative clause com-

TABLE 2  
Mean Percentage of Relative Clause Completions from Experiment 1 (Mean Percentage of Relative Clause Completions for the 16 Items Used in Experiment 2 in Parentheses)

Type of Context	Type of Sentence Fragment	
	Definite NP	"Only" + Definite NP
Past context	21 (18)	58 (57)
Future context	69 (73)	77 (80)

pletions. The percentage of relative clause completions for the four conditions is shown in Table 2. Sixteen items were selected for the second experiment and their means are shown in parentheses in Table 2.

The percentages of relative clause completions for all 20 items were analysed in an ANOVA with three factors: list (four lists), context type ("future" or "past") and noun phrase type ("definite NP" or "only + definite NP"). Separate ANOVAs were performed with subjects and items as random factors.

The subjects were more likely to interpret the verb at the end of the sentence fragment as a relative clause when it appeared in a future context, as shown by a main effect of context type [ $F(1,36) = 70.1$ ,  $MSe = 575$ ,  $P < 0.01$ ;  $F(1,16) = 74.45$ ,  $MSe = 279$ ,  $P < 0.01$ ]. The subjects were also more likely to interpret the sentence fragment as a part of a relative clause when the fragment began with the quantifier "only" than when it did not, as shown by a main effect of noun phrase type [ $F(1,36) = 40.72$ ,  $MSe = 1426$ ,  $P < 0.01$ ;  $F(1,19) = 58.81$ ,  $MSe = 165$ ,  $P < 0.01$ ]. There was also an interaction between context type and noun phrase type [ $F(1,36) = 26.97$ ,  $MSe = 328$ ,  $P < 0.01$ ;  $F(1,19) = 20.96$ ,  $MSe = 192$ ,  $P < 0.01$ ].

Simple effect tests revealed that context type affected both the definite noun phrases *without* the quantifier "only" [ $F(1,36) = 79.06$ ,  $MSe = 550$ ,  $P < 0.01$ ;  $F(1,19) = 99.08$ ,  $MSe = 217$ ,  $P < 0.01$ ] and the definite noun phrases with "only" [ $F(1,36) = 16.12$ ,  $MSe = 353$ ,  $P < 0.01$ ;  $F(1,19) = 12.78$ ,  $MSe = 254$ ,  $P < 0.01$ ]. This result is important because it suggests that the typical bias towards a past tense/main clause completion for these sentence fragments without a context can be reversed with a context that does not easily allow for the introduction of a past event. The effect of noun phrase type was significant in both the "past" contexts [ $F(1,36) = 57.76$ ,  $MSe = 503$ ,  $P < 0.01$ ;  $F(1,16) = 45.57$ ,  $MSe = 288$ ,  $P < 0.01$ ] and the "future" contexts [ $F(1,36) = 3.94$ ,  $MSe = 356$ ,  $P = 0.05$ ;  $F(1,16) = 8.77$ ,  $MSe = 69$ ,  $P < 0.01$ ].

## Discussion

The results clearly demonstrate that the temporal relationships in the discourse as established by tense influence how readers interpret fragments that are ambiguous between a main clause and a reduced relative clause. In the past-tense contexts, the subjects typically completed the fragments as main clauses, whereas in the future contexts most completions were reduced relative clauses.

The "only" manipulation also had the predicted effects.<sup>3</sup> Introducing the noun phrase with "only" shifted the preferred completion of the fragment from a main clause to a relative clause. As discussed earlier, this is predicted by the referential theory. This result establishes that the discourse entities the reader uses in establishing referential links from anaphoric NPs are, in part, determined by what information is in focus. This result has clear implications both for research that is designed to test the referential theory and for the theory itself. In particular, it is crucial to establish what information from the discourse is in focus when an anaphoric noun phrase is encountered in order to know what predictions the theory should make. The theory also has to be expanded to explicitly acknowledge interactions with discourse structure.

It could be argued that an explanation of the "only" effect does not require postulating an interaction with the information in the discourse. Rather, "only" itself introduces the relative clause bias. Note that this proposal would run counter to what the referential theory would predict. In the absence of context, the simplest assumption would be that the definite noun phrase is contrasted with some other unspecified entities of a different type. The assumption that the entities were of the same type (e.g. "only the student" as compared with "the rest of the students") would require the additional assumption that there was a distinguishing feature of the particular noun phrase under discussion. Thus, the referential theory would predict that "only" in a null context would not have an effect on the

<sup>3</sup>Although the effects of "only" were clearly significant, it is not particularly comforting for the referential theory that more than 40% of the "only" fragments were completed using the past tense. After examining the subjects' protocols more closely, it appeared that many subjects were not interpreting "only" as a quantifier, but rather as a conjunction. It was difficult to say definitively whether this was what subjects were doing in this study, so a study replicating the "only" manipulation was conducted, except this time each "only" was preceded by a subordinating word such as "But" or "However", as in *However, only the student spotted. . .*. This forces "only" to be interpreted as a quantifier. The subjects completed the fragments as relative clauses 24% of the time when the fragment did not contain an "only". In the presence of the "only", subjects completed the fragment as a relative clause 73% of the time. Clearly, the subjects were no longer treating the "only" as a conjunction, suggesting that "only" in context does induce the desired effect.

percentage of past-tense completions, and specifically that both noun phrase types would be completed as past-tense main clauses nearly all the time. We confirmed this prediction by testing six subjects using the same fragments, without contexts, that we had used in Experiment 1. A total of 59 of the 60 completions for the "only" fragments were completed as past-tense sentences, as opposed to 60 for the fragments without "only".<sup>4</sup> Clearly, then, the results for the "only" conditions in Experiment 1 were a result of interactions with the discourse context.

The results of the manipulation between future and past contexts, which are of central interest to the present article, clearly demonstrate that readers can use tense information, in a contextually sensitive manner, to resolve a structural ambiguity. It was important to establish this to test the general predictions that we derived from work on tense and discourse structure, and to validate our materials. However, the off-line nature of the completion task does not allow us to draw strong conclusions about how tense information is used in more normal on-line comprehension. It is possible, for instance, that the subjects arrived at participle completions only after first attempting a past-tense completion and then realising that their completion did not make sense given the discourse context. If readers and listeners typically do not establish temporal relations among events introduced into the discourse and those already in the model until relatively late in processing, then temporal contexts should not affect on-line syntactic ambiguity resolution. However, the incrementalist assumption, when coupled with what is known about the processing of other anaphoric expressions, would suggest that the temporal context should be accessed rapidly enough to influence syntactic ambiguity resolution.

## EXPERIMENT 2

This experiment examined reading times to reduced relative clauses, such as *The student spotted by the proctor. . .* in future and past contexts. Ferreira and Clifton (1986) demonstrated that readers experience tempor-

<sup>4</sup>Ni and Crain (1990) report that readers show a reduction in processing difficulty for relative clauses in isolation when they are preceded by the quantifier "only". Such a result suggests that readers may have initially interpreted the ambiguous phrase as a relative clause and not as a main clause. This result is not in conflict with our sentence completion data because of important differences between our stimuli and those used by Ni and Crain. They used plural noun phrases without determiners (e.g. *Only students spotted. . .*), whereas our stimuli all contained singular noun phrases with determiners (e.g. *Only the student spotted. . .*). Given our discussion above, one would expect that plural noun phrases like Ni and Crain's, when preceded by "only", should result in a bias towards a relative clause interpretation because a set, all of the same type, is explicitly established by the plural noun.

ary processing difficulty with phrases such as these. They found that reading times to the prepositional phrase *by the proctor* are longer in reduced relative clauses than in unambiguous unreduced relative clauses such as *The student who was spotted by the proctor . . .* Although there is a baseline complexity difference between reduced and unreduced relative clauses that is unrelated to ambiguity (Perlmutter & MacDonald, 1991; Tanenhaus, Carlson & Trueswell, 1989; Trueswell, Tanenhaus & Garnsey, 1988), at least some of the effect is clearly due to readers initially assuming that the verb *spotted* is a past-tense form. Evidence comes from studies that demonstrate that the "reduction effect" is smaller when the noun preceding the temporarily ambiguous verb is semantically against the past tense (Burgess, 1990; Tanenhaus et al., 1989; Trueswell et al., 1988).

Experiment 1 established that the temporal constraints provided by the future-tense discourse bias readers against taking an ambiguous verb such as *spotted* to be a past tense of a main clause verb. If the temporal context is immediately consulted at the verb, the context would bias the reader against a past-tense interpretation. This would reduce the processing difficulty that readers experience at the prepositional phrase for reduced relative clauses in future contexts as compared to reduced relative clauses in past contexts.

We also wanted to compare the reduced relative clauses against a baseline that did not contain a temporary ambiguity. The ideal baseline would be a reduced relative clause with a morphologically unambiguous verb, such as *The student seen by the proctor . . .* However, we were unable to construct enough of these materials. Therefore, we opted to use unreduced relative clauses. This is a relatively straightforward unambiguous control condition in the past contexts, where the appropriate unreduced form is clearly a past participle, as in (13):

13. *The student who was spotted by the proctor received a warning.*

In the future contexts, however, the reduced relative is compatible with several different unreduced forms, though they vary in felicity for different speakers. These include the past participle (*The student who was spotted by the proctor will receive a warning*), the present participle (*The student who is spotted . . .*), the future participle (*The student who will be spotted . . .*) and the future perfect participle (*The student who will have been spotted . . .*).

We chose to use the past participle form in the future contexts for two reasons: first, the baseline would be the same in both the future and past contexts and, secondly, it was this form that matched our intuitions about

how the reduced relatives were being interpreted in the future contexts.<sup>5</sup> As a result, two factors were manipulated in Experiment 2 (and in Experiment 3) in a crossed design: the time of the context (future or past) and the type of relative clause (reduced or unreduced past participle). However, during the review process, and in a subsequent informal survey, we learned that the past participle in future contexts is clearly infelicitous for speakers of British English and awkward for some speakers of American English. In order to obtain more systematic evidence about the felicity of the target sentences for our population of subjects, we conducted a rating study, which is described below.

### Rating Study

A total of 24 students at the University of Rochester rated the 16 target paragraphs used in Experiment 2 along with 24 filler paragraphs of varying felicity. Each subject was instructed to rate the naturalness of the final sentence in every paragraph. Naturalness was defined for the subject as how well, on first impression, the final sentence seemed to fit with the paragraph. The rating for each final sentence was on a scale of 1–5, in which 1 was "terrible" and 5 was "fine".

The results were as follows. For the past contexts, the reduced relative clauses received a mean rating of 4.1, whereas the rating for unreduced relatives was 4.4. For the future contexts, the mean rating for reduced relative clauses was 4.2, whereas the rating for the unreduced relatives was 3.9. An analysis of variance (ANOVA) was conducted on these ratings. The three factors were: list (four lists), clause type (reduced relative and unreduced relative) and context type ("past context" and "future context"). Overall, there was a marginal effect of context type [ $F(1,20) = 3.63$ ,  $MSe = 0.3316$ ,  $P < 0.1$ ] and no effect of clause type ( $F < 1$ ). The interaction between clause and context types was significant [ $F(1,20) = 10.99$ ,  $MSe = 0.2061$ ,  $P < 0.01$ ]. Simple effects revealed that the effect of clause type was significant in the past contexts [ $F(1,20) = 6.32$ ,  $MSe = 0.1854$ ,  $P < 0.05$ ] but not in the future contexts [ $F(1,20) = 2.43$ ,  $MSe = 0.4508$ ]. Also, there was no effect of context type for the reduced relative

<sup>5</sup>For those people who share our intuitions about relative clauses, the current time of reference, *R*, seems to be used as the "temporal anchor" instead of the time of speech, *S*. Thus, a past participle in a relative clause requires an antecedent event that occurs prior to the time of reference ( $E < R$ ), but not necessarily prior to time of speech ( $E < S$ ). Conversely, most speakers who find the past participle in the future context to be infelicitous seem to continue using the time of speech, *S*, as the temporal anchor in relative clauses, thus requiring an antecedent event that occurs prior to the time of speech ( $E < S$ ).



clauses ( $F < 1$ ). But, there was an effect of context type for the unreduced relative clauses [ $F(1,20) = 9.77$ ,  $MSe = 0.3466$ ,  $P < 0.01$ ].

The results are equivocal with respect to the appropriateness of the past participle as an unambiguous baseline for reduced relative clauses in future contexts. On the one hand, the subjects rated the unreduced form in the future contexts as fairly natural, and it did not differ from the reduced forms. On the other hand, it was clearly less felicitous than the past participle unreduced form in the past contexts. In light of these results, we will report and analyse the results of Experiment 2 and Experiment 3 using the full design, but we will also report comparisons that exclude the unreduced relative clauses in the future contexts.

## Method

*Subjects.* A total of 72 undergraduates from the University of Rochester participated in the experiment for course credit. All of the subjects were native speakers of English.

*Materials.* The experimental materials were generated from 16 of the texts used in the sentence completion study (Experiment 1). Minor modifications were made to some of the texts. All the target relative clauses contained disambiguating "by-phrases", similar to the ones shown in (14). The first factor in the experiment was whether the target relative clause appeared in a past context or a future context. The second factor was whether the relative clause was reduced or unreduced. An example of each target relative clause sentence is shown in (14). All the stimuli are contained in the Appendix.

- 14a. *The student spotted by the proctor will receive/received a warning.* (Reduced)  
 b. *The student who was spotted by the proctor will receive/received a warning.* (Unreduced)

Four presentation lists were constructed by combining the 16 experimental materials with 24 distractor tests for a total of 40 trials. Each target text was followed by at least one distractor text. The distractor texts contained a variety of event relations (future and past were used). The four conditions from each experimental set were rotated through the four lists. Each subject was presented with five practice trials and one of the four lists.

*Procedure.* The stimuli were presented on an IBM or IBM-compatible PC equipped with a colour monitor and Digity CTS timing system and response box. The monitor was set to a text mode of 80 characters per line. At the beginning of each trial, the entire text was displayed on the screen,

with each character (except spaces) covered by a single dash (-). The subject would then press a button marked SCROLL to uncover the first line of text. The subject would read the line and then press the SCROLL button to uncover the next line of text, while the previous line was covered up with dashes again. This was repeated until the last line of the text. On the last line, each button press uncovered only two words at a time. In the experimental trials, the last line of text always began with a relative clause target sentence. Reaction times were collected for the reading of each target sentence. After each text, a yes/no comprehension question was displayed on the screen and the subject responded by pressing YES or NO on the button box. The subjects were given feedback concerning whether their answer was correct.

We chose to present the target sentence two words at a time because of a combination of results obtained by Ferreira and Clifton (1986), Trueswell, Tanenhaus and Garnsey (1988) and Burgess (1990) in studies examining the role of thematic information in parsing of sentences with reduced relative clauses. Ferreira and Clifton (1986) monitored eye movements as subjects read sentences with reduced and unreduced relative clauses. In addition, they varied whether or not the first noun in the sentence was animate or inanimate. Example sentences are presented in (15):

- 15a. The defendant (that was) examined by the lawyer turned out to be unreliable.  
 b. The evidence (that was) examined by the lawyer turned out to be unreliable.

The eye-movement data showed garden-path effects for reduced relative clauses, regardless of the animacy of the noun. Moreover, animacy did not reduce the magnitude of the garden path. However, many of the inanimate nouns used by Ferreira and Clifton (1986) allowed plausible past-tense continuations. Trueswell et al. (1988) used the same design in an eye-tracking study, except they used inanimate nouns that did not allow a plausible past-tense completion. They found a garden-path effect only for the animate nouns. Burgess (1990) compared sentences similar to those used by Trueswell et al. (1988) and the sentences used by Ferreira and Clifton (1986) in self-paced reading studies using a moving window display with the text displayed in either one-word or two-word segments. In the two-word segments, the verb and "by" were presented in the same segment. With one-word presentation, Burgess found the same data pattern as Ferreira and Clifton (1986) with *both* sets of materials, namely a garden-path effect for reduced relative clauses regardless of the animacy of the preceding noun. However, with the two-word presentation, different results obtained with the two sets of materials. In the Ferreira and Clifton materials, there was a garden-path effect only for the animate and inani-

mate nouns with the more constraining materials. Thus Burgess' results with the two-word display map more closely onto the existing eye-movement data than do the results with the one-word display. Therefore, we decided to use the two-word display in the present experiment.

## Results

It was necessary to adjust reading times for variance contributed by string length because each particular position in a sentence differed in length, and because the sentence regions after the relative clause differed in length across context types. It is inappropriate to correct self-paced reading data by dividing by the number of characters (msec/character) because that correction assumes an intercept of zero for the function relating region length to reading times and thus overestimates the reading times for most regions (Ferreira & Clifton, 1986). We followed Ferreira and Clifton (1986) in assuming that reading time is normally a linear function of the number of characters, with an intercept equal to some time constant. A linear regression equation was computed for each subject expressing the subject's reading times as a function of the number of characters in a sentence region. Each regression included the reading times and character lengths of the regions shown in Fig. 1. Reading times from filler trials were not collected and therefore were not included in the regression. The regression equation was then used to obtain an expected reading time in milliseconds for each region within a target sentence. For each subject, the expected reading times were subtracted from the obtained reading times. A regression that included all subjects revealed that string length could account for 9% of the variance in millisecond reading time scores [ $R = 0.09$ ,  $F(1,4606) = 37.48$ ,  $MSe = 2566853$ ,  $P < 0.01$ ]. Scores more than 2.5 standard deviations above or below a subject's mean within a sentence region were truncated at the appropriate 2.5 standard deviation "cut-off" score.

Figure 1a presents the resulting "difference scores" of the four conditions for the two regions within the relative clause and for the two regions immediately following the relative clause. In general, reading time differences were negative in the first two regions, near zero in the third region and positive in the final region. Some negative and some positive reading time differences should be expected, because only reading times from the target relative clause sentences were entered into the linear regression. In fact, given our transformation, the average of all reading time differences should come out to be about 0 msec. The average is slightly less than zero because the 2.5 standard deviation adjustment was done after the regression. Thus, a negative score does not mean that the subjects were reading faster as compared to filler sentences; rather, they were reading faster as

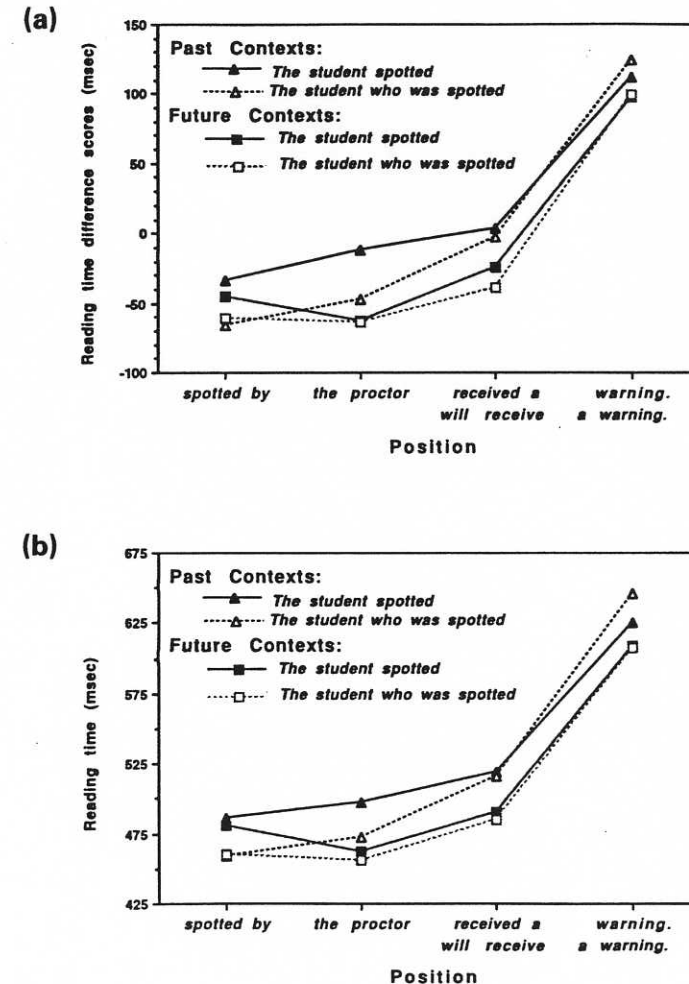


FIG. 1 Results of Experiment 2. (a) Mean difference scores in reading time for critical target sentence positions in future and past contexts; (b) mean reading times for critical target sentence positions in future and past contexts.

compared to some other region in the sentence. Figure 1b presents the reading time data in milliseconds, without adjustments for region length.

ANOVAs were conducted using both milliseconds per region and difference scores. Only the analyses using the difference scores will be reported. As expected, the unadjusted millisecond data were somewhat noisier because of the variance contributed by differing region lengths. However, all effects that were significant in the difference score analysis were either significant or approached significance in the ANOVA using unadjusted data.

Because of the questions raised about the appropriateness of the unreduced form in the future contexts, we will first report and analyse the results using the full design and then also report comparisons that exclude the unreduced relative clauses in the future contexts. As will become clear, both sets of statistics support the same conclusions.

### Complete Analysis

The four factors in the ANOVA were: list (four lists), region (verb + "by", definite noun phrase, verb + word), clause type (reduced relative clause and unreduced relative clause) and context type ("past context" and "future context").<sup>6</sup> Separate ANOVAs were performed with subjects and items as random factors.

There was an effect of region that was significant in the subject and item analyses [ $F(2,136) = 10.33$ ,  $MSe = 10477$ ,  $P < 0.01$ ;  $F(2,19) = 4.79$ ,  $P < 0.05$ ]. The interaction between context type and clause type was not significant [ $F(1,68) = 1.21$ ;  $F(1,12) = 1.95$ ]. However, there was a significant effect of clause type across the three regions [ $F(1,68) = 7.24$ ,  $MSe = 8998$ ,  $P < 0.01$ ;  $F(1,12) = 5.51$ ,  $MSe = 2556$ ,  $P < 0.05$ ]. The effect of context type was significant in the subject analysis [ $F(1,68) = 13.18$ ,  $MSe = 8461$ ,  $P < 0.01$ ] and approached significance in the item analysis [ $F(1,12) = 4.11$ ,  $MSe = 6086$ ,  $P = 0.07$ ].

*Analysis by region.* Separate analyses were conducted for each of the first three sentence regions shown in Fig. 1.

*Region 1.* There was a significant effect of clause type in the first sentence region [ $F(1,68) = 8.06$ ,  $MSe = 5042$ ,  $P < 0.01$ ;  $F(1,12) = 10.06$ ,  $MSe = 888$ ,  $P < 0.01$ ]. There was no effect of context type [ $F(1,68) = 0.14$ ;  $F(1,12) = 0.06$ ] and the interaction between context and clause

type was not significant [ $F(1,68) = 0.37$ ;  $F(1,12) = 1.25$ ]. However, simple effects revealed that there was an effect of clause type in the past contexts [ $F(1,68) = 9.01$ ,  $MSe = 3961$ ,  $P < 0.01$ ;  $F(1,12) = 12.20$ ,  $MSe = 645$ ,  $P < 0.01$ ], but not in the future contexts [ $F(1,68) = 1.43$ ,  $MSe = 6488$ ;  $F(1,12) = 1.99$ ,  $MSe = 1014$ ].

*Region 2.* In the second region, which contained the head noun phrase of the prepositional phrase, there was a significant context  $\times$  clause type interaction in both the subject and item analyses [ $F(1,68) = 5.12$ ,  $MSe = 4051$ ,  $P < 0.05$ ;  $F(1,12) = 6.34$ ,  $MSe = 726$ ,  $P < 0.05$ ]. There was also a significant effect of context type [ $F(1,68) = 18.66$ ,  $MSe = 4220$ ,  $P < 0.01$ ;  $F(1,12) = 9.40$ ,  $MSe = 1850$ ,  $P < 0.01$ ] and a significant effect of clause type [ $F(1,68) = 4.35$ ,  $MSe = 5288$ ,  $P < 0.05$ ;  $F(1,12) = 5.43$ ,  $MSe = 945$ ,  $P < 0.05$ ]. Simple effects tests revealed that the interaction between context type and clause type was due to a significant effect of clause type for the sentences that appeared in the past contexts [ $F(1,68) = 7.23$ ,  $MSe = 6043$ ,  $P < 0.01$ ;  $F(1,12) = 6.84$ ,  $MSe = 1423$ ,  $P < 0.05$ ], whereas there was no effect of clause type for sentences that appeared in the future contexts [ $F(1,68) = 0.01$ ;  $F(1,12) = 0.03$ ].

*Region 3.* In the third region, there was only a significant effect of context type in the subject analysis [ $F(1,68) = 8.19$ ,  $MSe = 9117$ ,  $P < 0.01$ ], but not in the item analysis [ $F(1,12) = 1.30$ ]. No other effects or interactions were reliable.

### Comparisons Excluding Unreduced Relatives in Future Contexts

Reading time difference scores in msec and reading times in msec for the reduced relative clauses are re-plotted in Figs 2a and 2b respectively. Looking first at the reading times to sentences in the *past contexts*, there was a main effect of clause type across the three regions [ $F(1,68) = 7.57$ ,  $MSe = 8413$ ,  $P < 0.01$ ;  $F(1,12) = 5.43$ ,  $MSe = 2594$ ,  $P < 0.05$ ], with reduced relatives having longer overall reading times than unreduced relatives. Separate analyses were conducted for each of the first three sentence regions shown in Fig. 2. There was a significant effect of clause type in past contexts in the first sentence region [ $F(1,68) = 9.01$ ,  $MSe = 3961$ ,  $P < 0.01$ ;  $F(1,12) = 12.20$ ,  $MSe = 646$ ,  $P < 0.01$ ] and the second region [ $F(1,68) = 7.23$ ,  $MSe = 6043$ ,  $P < 0.01$ ;  $F(1,12) = 6.84$ ,  $MSe = 1423$ ,  $P < 0.05$ ], whereas there was no effect of clause type in the third position ( $F_1$  and  $F_2 < 1$ ).

Turning to the reading times for *reduced* relative clauses in past and future contexts, there was a main effect of context type across the three

<sup>6</sup>Analyses of the final region of Fig. 1 and the region before the first region shown in Fig. 1 showed no significant differences or interactions.

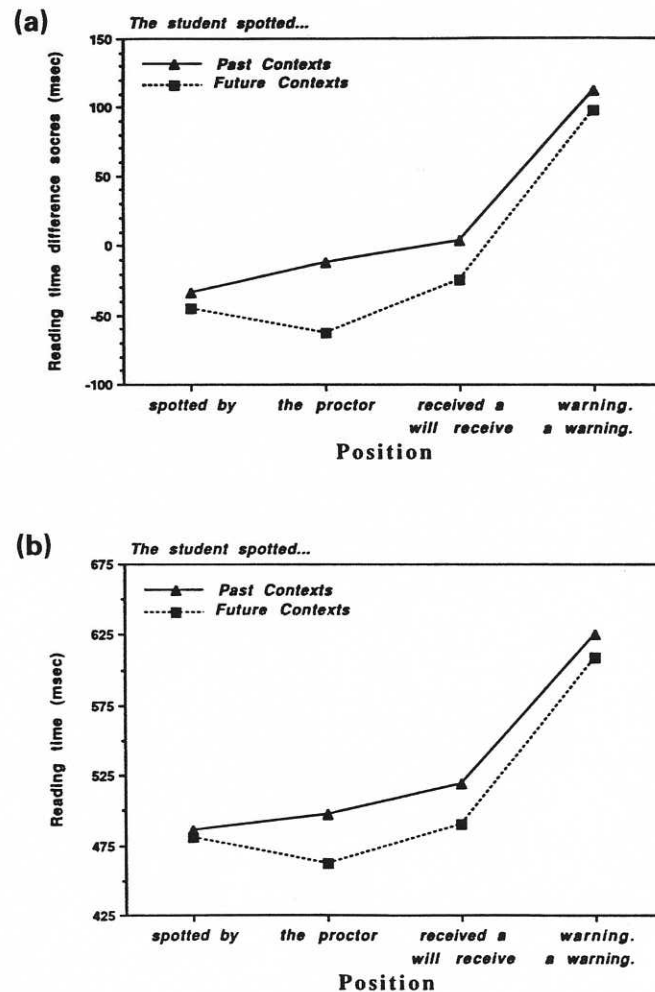


FIG. 2 Results of reduced relatives in Experiment 2. (a) Mean difference scores in reading time for critical target sentence positions in reduced relative clauses; (b) mean reading times for critical target sentence positions in reduced relative clauses.

regions [ $F(1,64) = 8.04$ ,  $MSe = 11791$ ,  $P < 0.01$ ;  $F(1,12) = 6.10$ ,  $MSe = 3522$ ,  $P < 0.05$ ], with reduced relatives in past contexts having longer reading times than reduced relatives in future contexts. Separate analyses were conducted for each of the first three regions shown in Fig. 1. There was no significant effect of context type in the reduced relatives in the first sentence region [ $F(1,64) = 1.17$ ,  $MSe = 3488$ ;  $F(1,12) = 0.55$ ,  $MSe = 1613$ ], whereas there was a significant effect of context type in the reduced relatives for the second region [ $F(1,64) = 19.33$ ,  $MSe = 4666$ ,  $P < 0.01$ ;  $F(1,12) = 14.07$ ,  $MSe = 1418$ ,  $P < 0.01$ ] but not the third region [ $F(1,64) = 2.01$ ,  $MSe = 14263$ ;  $F(1,12) = 0.96$ ,  $MSe = 7188$ ].

A set of planned comparisons was also made between the reduced relatives in the future contexts and the unreduced relatives in the past contexts. The three factors in the ANOVA were: list (four lists), region (verb + "by", definite noun phrase, verb + word) and target type (reduced relative clauses in future contexts and unreduced relative clauses in past contexts). Separate ANOVAs were performed with subjects and items as random factors. Across the first three sentence regions, there was no effect of target type ( $F_1$  and  $F_2$  both  $< 1$ ). In the separate analysis for each sentence region, there was an effect of target type in the first sentence region for the subject analysis, but not for the item analysis [ $F(1,68) = 4.93$ ,  $MSe = 3185$ ,  $P < 0.05$ ;  $F(1,12) = 2.92$ ,  $MSe = 1192$ ]. There were no effects of target type in the second sentence region [ $F(1,68) = 1.94$ ;  $F(1,12) = 1.90$ ] or in the third sentence region [ $F(1,68) = 1.47$ ;  $F(1,12) = 0.87$ ].

## Discussion

These results demonstrate that readers immediately evaluate tense with respect to the temporal parameters of the discourse and that temporal information from the discourse context is used in syntactic ambiguity resolution. Reading times to reduced relative clauses were faster in the future contexts than in the past contexts. Moreover, reading times to reduced relative clauses in the future contexts did not differ from reading times to unreduced relative clauses in the past contexts, whereas reading times to reduced relatives in the past contexts did.

The future context did not, however, completely eliminate the processing difficulty associated with reduced relative clauses. At the first segment that we examined – the verb + "by" segment – reading times to the reduced relatives in future contexts were longer than the unreduced forms, though the difference was significant only in the subject analysis. Also at this first segment, reading times to reduced relatives in future and past contexts did not differ.

There are several possible explanations for why readers experience some processing difficulty at the verb + "by" region, which our data, unfortunately, do not distinguish among. The first possibility is that only the past-tense form of the verb was initially evaluated against the context, either because it becomes available more rapidly than the less frequent participial form, or because readers initially follow a structurally defined parsing strategy, such as minimal attachment (Frazier & Fodor, 1978).

Alternatively, the future context may have enabled readers to parse the ambiguous fragment initially as a reduced relative clause. Why, then, would reading times be longer at the verb + "by" region for the reduced relatives as compared to the unreduced relatives? One possibility is that more processing is localised at the verb for reduced relative clauses. In a reduced relative clause, the first information that the structure is a relative clause comes from the verb. In contrast, in an unreduced relative clause, this information is provided two words earlier, at the relative pronoun *who*. Moreover, the auxiliary *was* in the unreduced relative clause provides the reader with information about tense that is not available in the reduced relative. Recall that a reduced relative clause is ambiguous with respect to tense (i.e. *The student spotted by the proctor* can be *The student who will be spotted . . .*, *The student who was spotted . . .*, etc). We argued earlier that information about tense in a relative clause is useful in locating the appropriate antecedent event. If this is correct, then the processing load would be expected to increase when the tense is not explicitly present. One or both of these factors might make reduced relative clauses harder to process at the verb than unreduced relatives, even when the reduced relative is initially parsed correctly.<sup>7</sup>

In order to test these conjectures, it will be necessary to compare reduced relative clauses with morphologically ambiguous and unambiguous verbs (e.g. *The student spotted by . . .* and *The student seen by . . .*) in future and past contexts. If readers initially access the past-tense form, regardless of context, then reading times at the verb + "by" region would be longer for the ambiguous verbs in both contexts. If, however, the future context prevents access to the past-tense form, then reading times to the unambiguous and ambiguous forms should be similar in future contexts. We are currently attempting to develop a set of materials using ambiguous

<sup>7</sup>It should be pointed out that this explanation assumes that the locus of the processing difficulty is different for the reduced relative clauses in the past contexts than in the future contexts. In the future contexts, a reduced relative is difficult because the reader is establishing a relative clause, whereas in the past contexts, a reduced relative is difficult because the reader incorrectly selected the past-tense interpretation. Obviously, additional research will be necessary to determine if the locus of the processing difficulty is different in these two conditions.

and unambiguous reduced relative clauses that can be placed in contexts similar to the ones used in the present study.

Another possibility, which is easier to evaluate given the current materials, is that the small effect found in the future contexts is due to an inference that the reader has to make to relate the verb in the target sentence to the event that it refers to in the discourse model. The reason for this is that a different verb was used in the relative clause than in the sentence originally introducing the event. Altmann (1988) has demonstrated that there is a cost associated with using different verbs to refer to the same event, even when both are nearly synonymous. Presumably, by the time the reader gets to the verb in the unreduced form, he or she would already be aware that a direct reference to an event is being attempted. Since the discourse provides only one possible event entity involving the initial noun phrase as an object, the inference process would be well underway. If an "inferencing" explanation is correct, then the effect found in the future contexts would be decreased, or eliminated, when the same verb is used both in the relative clause and in the context. A second self-paced study, Experiment 3, was conducted to test this hypothesis. In Experiment 3, the method of presentation and materials were identical to Experiment 2, except that now the verb that originally introduced the event in the context was replaced with the verb that was used in the relative clause.

### EXPERIMENT 3

#### Method

*Subjects.* A total of 40 undergraduates from the University of Rochester participated in the experiment for course credit. All of the subjects were native speakers of English.

*Materials.* The experimental materials were identical to those used in Experiment 2, except that the verb used in the relative clause was now identical to the one used in the sentence that originally introduced the event. This was done by replacing the verb that originally introduced the event in the context with the verb used in the relative clause (see Table 3 for a complete example of the materials).

Four presentation lists were constructed by combining the 16 experimental materials with 24 distractor texts for a total of 40 trials. Each target text was followed by at least one distractor text. The distractor texts contained a variety of event relations (future and past were used). The four conditions from each experimental set were rotated through the four lists. Each subject was presented with five practice trials and one of the four lists.

TABLE 3  
An Example of the Materials for Experiment 3

Example	
Past context	Several students were sitting together taking an exam yesterday. A proctor came up and spotted one of the students cheating.
Future context	Several students will be sitting together taking an exam tomorrow. A proctor will come up and spot one of the students cheating.
Relative clause	The student (who was) spotted by the proctor (received)/(will receive) a warning.

*Procedure.* The self-paced reading procedure was identical to the one used in Experiment 2.

## Results

As in Experiment 2, the reading times were adjusted for the variance contributed by region lengths. Figure 3a presents the resulting "difference scores" for each region. The same basic data pattern was obtained as that in Experiment 2. Figure 3b presents the reading time data in milliseconds, without adjusting for region length.

The data for these sentences were analysed in an analysis of variance. ANOVAs were conducted using both milliseconds per region and difference scores. Only the analyses using the difference scores will be reported. The same basic data pattern was obtained in both sets of analyses. All significant effects reported in this section were also significant or approached significance in an analysis of variance of the millisecond reading time data. Again, as expected, the unadjusted millisecond data were somewhat noisier because the variance contributed by differing regions lengths had not been removed.

The four factors in the ANOVA were: list (four lists), region (verb + "by", definite noun phrase, verb + word), clause type (reduced relative clause and unreduced relative clause) and context type ("past context" and "future context").<sup>8</sup> Separate ANOVAs were performed with subjects and items as random factors.

As in Experiment 2, we will first report analyses that include all four conditions of the experiment and then we will present comparisons that do

<sup>8</sup>Analyses of the final region of Fig. 3 and the region before the first region shown in Fig. 2 showed no significant differences or interactions.

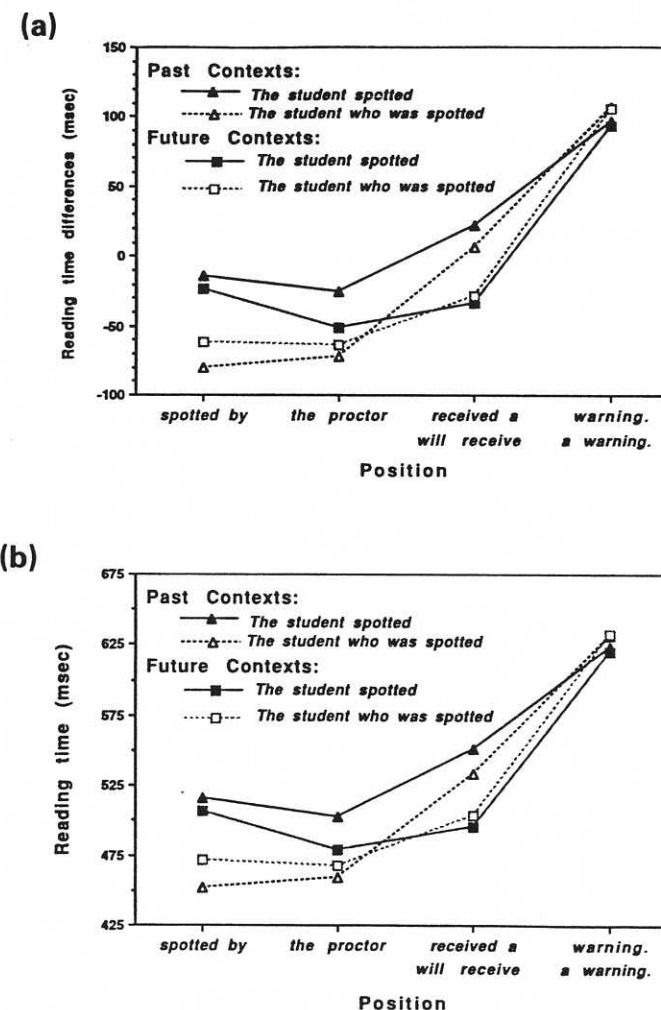


FIG. 3 Results of Experiment 3. (a) Mean difference scores in reading time for critical target sentence positions in future and past contexts; (b) mean reading times for critical target sentence positions in future and past contexts.

not involve unreduced relative clauses in future contexts. Both sets of statistics support the same conclusions.

### Complete Analysis

There was an effect of region that was significant in the subject and item analyses [ $F(1,17) = 11.85$ ,  $MSe = 7785$ ,  $P < 0.01$ ;  $F(2,24) = 5.22$ ,  $MSe = 2037$ ,  $P < 0.05$ ]. Unlike Experiment 2, the interaction between context type and clause type was significant in the subject analysis, but marginal in the item analysis [ $F(1,36) = 4.60$ ,  $MSe = 4830$ ,  $P < 0.05$ ;  $F(1,12) = 3.92$ ,  $MSe = 2272$ ,  $P < 0.1$ ]. There was also a significant effect of clause type across the three regions [ $F(1,36) = 15.10$ ,  $MSe = 6571$ ,  $P < 0.01$ ;  $F(1,12) = 7.22$ ,  $MSe = 5512$ ,  $P < 0.05$ ]. The effect of context type was also significant [ $F(1,36) = 6.21$ ,  $MSe = 5361$ ,  $P < 0.05$ ;  $F(1,12) = 5.84$ ,  $MSe = 2270$ ,  $P < 0.05$ ]. The interaction between clause type and context type occurred because there was an effect of clause type for the past contexts [ $F(1,36) = 18.12$ ,  $MSe = 5942$ ,  $P < 0.01$ ;  $F(1,12) = 13.87$ ,  $MSe = 3113$ ,  $P < 0.01$ ], but not for the future contexts [ $F(1,36) = 2.52$ ,  $MSe = 5459$ ;  $F(1,12) = 1.19$ ,  $MSe = 4671$ ].

*Analysis by region.* Separate analyses were conducted for each of the first three sentence regions shown in Fig. 3.

*Region 1.* There was a significant effect of clause type in the first sentence region [ $F(1,36) = 35.77$ ,  $MSe = 3038$ ,  $P < 0.01$ ;  $F(1,12) = 21.47$ ,  $MSe = 2030$ ,  $P < 0.01$ ]. There was no effect of context type [ $F(1,36) = 0.22$ ;  $F(1,12) = 0.27$ ] and the interaction between context and clause type was not significant [ $F(1,36) = 2.29$ ,  $MSe = 3509$ ;  $F(1,12) = 3.06$ ,  $MSe = 1043$ ].

*Region 2.* In the second region, there was a context  $\times$  clause type interaction that was significant in the subject analysis [ $F(1,36) = 4.67$ ,  $MSe = 2297$ ,  $P < 0.05$ ] and approached significance in the item analysis [ $F(1,12) = 3.20$ ,  $MSe = 1363$ ,  $P < 0.1$ ]. There was no significant effect of context type [ $F(1,36) = 0.63$ ;  $F(1,12) = 2.76$ ,  $MSe = 463$ ]. There was a significant effect of clause type [ $F(1,36) = 11.54$ ,  $MSe = 2939$ ,  $P < 0.01$ ;  $F(1,12) = 5.94$ ,  $MSe = 2275$ ,  $P < 0.05$ ]. Simple effects tests revealed that the interaction between context type and clause type was due to a significant effect of clause type for the sentences that appeared in the past contexts [ $F(1,36) = 12.13$ ,  $MSe = 3412$ ,  $P < 0.01$ ;  $F(1,12) = 8.39$ ,  $MSe = 1980$ ,  $P < 0.05$ ], whereas there was no effect of clause type for sentences that appeared in the future contexts [ $F(1,36) = 1.78$ ;  $F(1,12) = 0.76$ ].

*Region 3.* In the third region, there was only a significant effect of context type in the subject analysis [ $F(1,36) = 14.86$ ,  $MSe = 5617$ ,  $P < 0.01$ ;  $F(1,12) = 5.08$ ,  $MSe = 6561$ ,  $P < 0.05$ ]. No other effects or interactions were significant.

### Comparisons Excluding Unreduced Relatives in Future Contexts

Reading time difference scores and reading times in milliseconds for the reduced relative clauses are re-plotted in Figs 4a and 4b respectively. First, looking at the reading times of sentences in the *past contexts*, there was a main effect of clause type across the three regions [ $F(1,36) = 18.12$ ,  $MSe = 5942$ ,  $P < 0.01$ ;  $F(1,12) = 13.87$ ,  $MSe = 3113$ ,  $P < 0.01$ ], with reduced relatives having longer overall reading times than unreduced relatives. Separate analyses were conducted for each of the first three sentence regions shown in Fig. 4. There was a significant effect of clause type in past contexts in the first sentence region [ $F(1,36) = 31.34$ ,  $MSe = 2804$ ,  $P < 0.01$ ;  $F(1,12) = 55.69$ ,  $MSe = 631$ ,  $P < 0.01$ ] and the second region [ $F(1,36) = 12.13$ ,  $MSe = 3412$ ,  $P < 0.01$ ;  $F(1,12) = 8.39$ ,  $MSe = 1980$ ,  $P < 0.05$ ], whereas there was no effect of clause type in the third position ( $F_1$  and  $F_2 < 1$ ).

Now looking only at the reading times for *reduced* relative clauses (in past and future contexts), there was a main effect of context type across the three regions [ $F(1,36) = 9.31$ ,  $MSe = 5903$ ,  $P < 0.01$ ;  $F(1,12) = 6.63$ ,  $MSe = 3307$ ,  $P < 0.05$ ], with reduced relatives in past contexts having longer reading times than reduced relatives in future contexts. Separate analyses were conducted for each of the first three regions shown in Fig. 4. There was no significant effect of context type in the reduced relatives in the first sentence region ( $F_1$  and  $F_2$  both  $< 1$ ), whereas there was a significant effect of context type in the reduced relatives for the second region [ $F(1,36) = 4.11$ ,  $MSe = 3141$ ,  $P < 0.05$ ;  $F(1,12) = 7.31$ ,  $MSe = 708$ ,  $P < 0.01$ ] and the third region [ $F(1,36) = 7.62$ ,  $MSe = 8228$ ,  $P < 0.01$ ;  $F(1,12) = 5.58$ ,  $MSe = 4476$ ,  $P < 0.05$ ].

A set of planned comparisons were also made between the reduced relatives in the future contexts and the unreduced relatives in the past contexts. The three factors in the ANOVA were: list (four lists), region (verb + "by", definite noun phrase, verb + word) and target type (reduced relative clauses in future contexts and unreduced relative clauses in past contexts). Separate ANOVAs were performed with subjects and items as random factors. Across the first three sentence regions, there was no effect of target type [ $F(1,36) = 1.28$ ;  $F(1,12) = 0.79$ ]. In the separate analysis for each sentence region, there was an effect of target type in the first

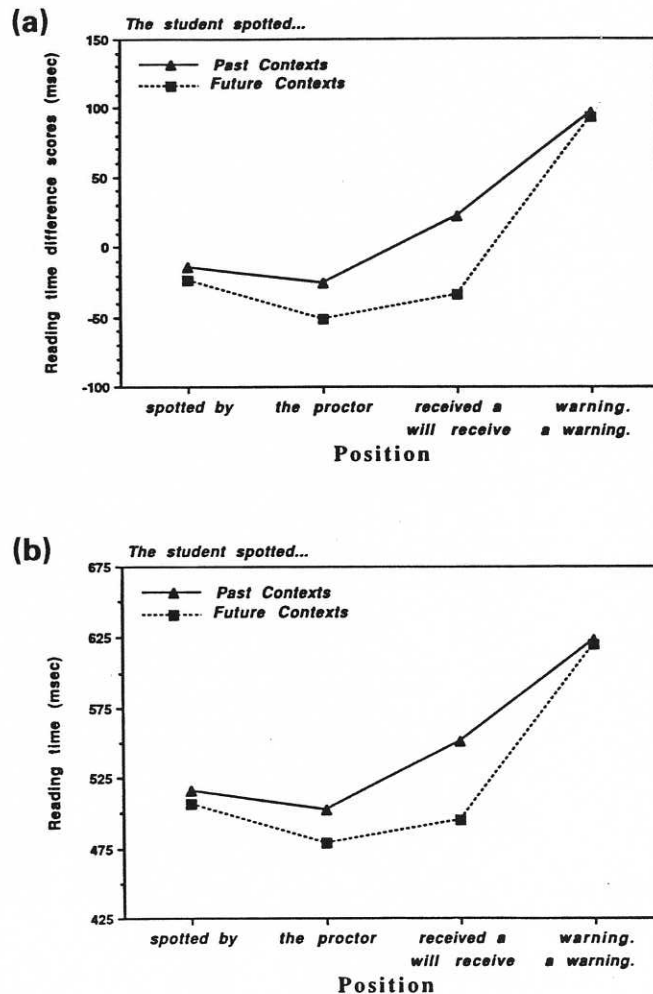


FIG. 4 Results of reduced relatives in Experiment 3. (a) Mean difference scores in reading time for critical target sentence positions in reduced relative clauses; (b) mean reading times for critical target sentence positions in reduced relative clauses.

sentence region [ $F(1,36) = 15.97$ ,  $MSe = 4050$ ,  $P < 0.01$ ;  $F(2,12) = 11.64$ ,  $MSe = 2227$ ,  $P < 0.01$ ]. There was no effect of target type in the second sentence region [ $F(1,36) = 2.01$ ;  $F(2,12) = 2.02$ ]. The effect of target type in the third region was significant in the subject analysis [ $F(1,36) = 4.74$ ,  $MSe = 6976$ ,  $P < 0.05$ ] and approached significance in the item analysis [ $F(2,12) = 3.80$ ,  $MSe = 3450$ ,  $P < 0.1$ ].

#### Comparisons Between Experiment 3 and Experiment 2

In order to compare the data pattern of this experiment with that found in Experiment 2, an analysis of variance was conducted comparing the item means of both experiments. The three factors in the ANOVA were: experiment (Experiment 2 and Experiment 3), region (verb + "by", definite noun phrase, verb + word), target type (reduced and unreduced relative clauses) and context type (future and past). None of the effects in either study interacted with experiment, except for the effect of clause type at the verb + "by" region [ $F(1,15) = 5.16$ ,  $MSe = 1264$ ,  $P < 0.05$ ]. This interaction occurred because the difference in reading times between reduced and unreduced relative clauses at the "verb + by" segment was greater in Experiment 3 than Experiment 2.

#### Discussion

The question of interest was whether in future contexts the difference between reduced and unreduced relative clauses at the "verb + by" segment would be eliminated when the target sentence and the context used the same verb. However, contrary to the predictions made by the inference hypothesis, the use of the same word actually *increased* the difference between the reduced and unreduced forms in the future contexts, and in the past contexts as well.

It is not entirely clear why repeating the verb should have increased processing difficulty for reduced relative clauses. One possibility is that when a morphologically ambiguous verb is encountered, the underlying active and passive (participial) forms of the verb are activated in parallel, similar to other lexical ambiguities. The alternative forms would then compete with one another, with the more frequent form being accessed first and inhibiting or delaying access of the less frequent form. In this experiment, the verb in the reduced relative clause was used in the active form in the immediately preceding sentence. As a consequence, this form would still have been highly activated and thus would have delayed or inhibited retrieval of the participial form. This would not have occurred in the unreduced relative clauses because the preceding *was* would facilitate access to the participial form, perhaps by inhibiting the active form. It is



important to note that many other structural ambiguities also hinge upon some type of morphological or lexical ambiguity. Thus, evidence that the processing of reduced relative clauses is influenced by the availability of alternative lexical forms may have broader implications for syntactic ambiguity resolution.

This experiment also replicated the temporal context effects found in Experiment 2. Reduced relatives were read faster in future contexts than in past contexts, again indicating that readers immediately processed tense in relation to the temporal parameters of the discourse.

### GENERAL DISCUSSION

The present research combined ideas from recent work on tense and discourse with the incrementalist assumption that a mental model of the discourse is continuously updated during sentence processing, to predict that the processing of reduced relative clauses would be affected by the tense of the preceding discourse. This prediction was confirmed. When subjects read contexts in which events were established as occurring in the past, they completed ambiguous sentence fragments as past-tense main clauses rather than as relative clauses. In contrast, when subjects read contexts in which events were established as occurring in the future, they completed ambiguous sentence fragments as reduced relative clauses with participial verbs. During self-paced reading, the subjects had less difficulty processing reduced relative clauses when they appeared in future contexts than when they appeared in past contexts.

As we argued in the Introduction, the future tense establishes temporal relations between the time of speech and the time of reference ( $S < R$ ) that do not allow the reader to introduce a past event from a main clause without reconstructing the discourse. However, the past tense establishes temporal relations between the time of speech and time of reference ( $R < S$ ) that allow the introduction of a past event from a main clause without any changes to the basic structure of the discourse. What these results show, then, is that a tensed verb is immediately interpreted against the backdrop of the temporal parameters established in the discourse model. These results complement recent work on the effects of referential context on syntactic ambiguity resolution as well as other work that emphasises the continuous and incremental nature of comprehension (e.g. Altmann & Steedman, 1988; Marslen-Wilson & Tyler, 1987).

These results are also relevant to the ongoing debate about whether or not there is an initial stage in syntactic ambiguity resolution that is sensitive to syntactic category information only (Altmann & Steedman, 1988; Crain & Steedman, 1985; Frazier, 1978, 1987; Frazier & Fodor, 1978; Tarraban & McClelland, 1988). For example, the most recent version of the influential "garden-path" model developed by Frazier and colleagues assumes a serial

parser in which "attachment" decisions are guided by simplicity-based parsing strategies that make use of only major syntactic category information (Ferreira & Henderson, 1991; Frazier, 1989). In this model, contextual information can help filter and revise incorrect analyses, but it cannot prevent an initial garden path from occurring whenever a local ambiguity must be resolved in favour of the syntactically more complex structure. While the studies presented here demonstrate that temporal information from the discourse is rapidly used in syntactic ambiguity resolution, they do not provide clear evidence about whether these effects occurred during the earliest stages in parsing. Proponents of the garden-path theory could interpret the difference between reduced and unreduced relative clauses in the future contexts as evidence for a brief garden path. However, it would be premature to do so because of the differences between reduced and unreduced relative clauses that were discussed earlier. Additional control conditions need to be investigated before this effect can be safely attributed to a structurally based garden path.

The primary contribution of the present work is to establish that readers immediately consult the temporal structure of the discourse during sentence processing. Minimally, the present studies demonstrate that readers establish temporal relations between an event being introduced in a sentence and events already established in the context by making use of tense and temporal parameters such as time of reference and time of speech. It is possible that reference to the event structure of the discourse model is actually quite limited during sentence processing, and that only these temporal parameters are consulted when a tensed verb is encountered. However, it seems likely that readers attempt a more detailed updating of the discourse model in which the event being denoted by the verb is related to other relevant events in the discourse. If this is the case, then real-world knowledge that is relevant to determining the temporal and causal relationships between events might also be consulted during immediate sentence processing. A likely candidate would be information about the plausible antecedents and consequences of an event (cf. Moens & Steedman, 1988). Whether information like this is immediately used during sentence processing remains a question for future research.

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## APPENDIX: STIMULI FOR EXPERIMENT 2

The first item is given in all four conditions: past context with reduced and unreduced relative clause types and future context with reduced and unreduced clause types. The remaining items are all given with a past context and a reduced relative clause. In the experiment, line breaks were placed in natural looking positions so that it would result in the target sentence beginning on the final line.

- Several students were sitting together taking an exam in a large lecture hall earlier today.  
A proctor noticed one of the students cheating.  
The student (who was) spotted by the proctor received a warning.  
Several students will be sitting together taking an exam in a large lecture hall later today.  
A proctor will notice one of the students cheating.  
The student (who was) spotted by the proctor will receive a warning.
- Several visitors were waiting in an executive's front office last week.  
A secretary came up to one of the visitors and said hello.  
The visitor greeted by the secretary stood up slowly.
- Several heavily armed soldiers were exploring a bombed out building in Beirut yesterday.  
A terrorist came out of nowhere and fired a gun at one of the soldiers.  
The soldier shot by the terrorist called out for help.
- Last week several consultants were each waiting to hear about an executive's decision.  
The executive telephoned and left a message for one of the consultants.  
The consultant called by the executive never got the message.
- Some sick children were in a hospital ward last week.  
A nurse came up and wrapped her comforting arms around one of the children.  
The child hugged by the nurse felt much better.
- Last Tuesday, all the prisoners were standing in line for dinner.  
A guard came up and shoved one of the prisoners.  
The prisoner pushed by the guard drew a knife.
- Several old men were sitting on a park bench last Sunday.  
A young child ran up and accidentally startled one of the men.  
The man frightened by the child got very angry.
- This past Easter, many worshippers were gathered to see the Pope.  
The Pope placed his hand on the forehead of one of the worshippers.  
The worshipper touched by the Pope began to cry.
- Last Monday afternoon, several teenagers were playing basketball in a vacant lot.  
A beautiful young woman began to walk towards one of the players.  
The player approached by the woman became very nervous.
- A motorcycle gang was sitting around a table in a bar last night.  
A warrant officer walked in and glanced over at the men.  
He suddenly realised that he knew one of the men from a wanted poster that he saw earlier.  
The man recognised by the officer ran out of the bar.
- At last night's game, both basketball referees were in a heated argument with the home team's coach.  
The coach became angry and started taunting one of the referees with ethnic slurs.  
The referee insulted by the coach threw him out of the game.

12. Quite a few teenagers were hanging out at a street corner yesterday.  
A cop came along and suddenly threatened one of the teenagers.  
The teenager confronted by the cop decided to move along.
13. The boss of a large company interviewed several job applicants two days ago.  
The boss got along well with one of the applicants.  
The applicant liked by the boss got the job.
14. Several old ladies were standing in front of a supermarket with their groceries yesterday.  
A bag boy came up and helped one of the old ladies, but he unfortunately dropped the groceries.  
The lady assisted by the boy remained surprisingly calm.
15. Many illegal aliens were trying to cross the border last night.  
A patrol guard, scanning the area with his binoculars, noticed one of the aliens.  
The alien spotted by the guard managed to get across anyway.
16. A bunch of girls were playing ball in a playground yesterday.  
A bully came up and for no apparent reason punched one of the girls in the mouth.  
The girl hit by the bully called out for a teacher.