Consulting temporal context during sentence comprehension: Evidence from the monitoring of eye movements in reading

John C. Trueswell
trueswel@psych.rochester.edu

and

Michael K. Tanenhaus
mtan@psych.rochester.edu

Department of Psychology
University of Rochester
Rochester, NY 14627

Abstract

An important aspect of language processing is the comprehender's ability to determine temporal relations between an event denoted by a verb and events already established in the discourse. This often requires the tense of a verb to be evaluated in relation to specific temporal discourse properties. We investigate the time course of this process by examining how the temporal properties of a discourse influence the initial processing of temporarily ambiguous reduced relative clauses. Much of the empirical work on the reading of reduced relative clauses has revealed that readers experience a large mis-analysis effect (or 'garden-path') in reduced relatives like "The student spotted by the proctor received a warning" because the reader has initially interpreted the verb "spotted" as a past tense verb in a main clause. Recent results from an eye movement study are provided which indicate that this mis-analysis of relative clauses can be eliminated when the temporal constraints of a discourse do not easily permit a main clause past tense interpretation. Such a finding strongly suggests that readers process tense in relation to the temporal properties of the discourse, and that constraints from these properties can rapidly influence processing at a structural level.

Introduction

Understanding a discourse requires the listener or reader to develop and maintain a representation of the events and entities under discussion. In addition, many linguistic expressions can only be interpreted by making reference to information in this discourse representation. It is this contextually dependent property of language which motivates incremental models of sentence processing. Such models propose that, as a sentence unfolds in time, readers and listeners make rapid commitments to interpretations by incrementally evaluating linguistic input in relation to some portion of the discourse (Crain & Steedman, 1985; Altmann & Steedman, 1988; Ni and Crain, 1990). In this way, sentence processing is made sensitive to the constraints provided by various aspects of the discourse. Most of the empirical evidence supporting this approach focuses on the contextual dependencies of definite noun phrases. Such work provides evidence suggesting that the reference to individuals, sets and their properties via noun phrase expressions influences sentence processing at a structural level. We report here complementary research which examines whether similar processes apply to the establishment of, and reference to, temporal and event discourse entities.

Within computational linguistics, there is an increasing interest in the topic of tense and aspect and its relation to discourse processing problems (Webber, 1988). In particular, researchers wish to characterize, at a processing level, how to interpret and represent complex events in a changing discourse. Two issues of critical importance are the problem of encoding new event descriptions (typically denoted by tense-marked verb phrases), and the problem of manipulating references to events already established in the discourse. 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). In fact, Webber (1988) has recently argued that tense, by definition, should be considered a discourse anaphor, similar to that of a definite noun phrase.

Most models of tense interpretation take as their starting point the work of Hans Reichenbach (1947),who proposed that interpretation of tense requires three separate semantic entities: time of speech (S), time of event (E), and time of reference (R). 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, 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.

Without going into the details of how S and R are established for a current discourse segment (see Trueswell and Tanenhaus, 1991), consider the following sentence pair, in which the first sentence establishes a particular relation between S and R.

1a. Tomorrow, Ms. Brown will announce she is running for president. (R > S).
b. She ran for president in the last election as well.

The notation (R>S) indicates that sentence (1a) establishes a time of reference for the current discourse segment which is ahead of the current time of speech ("now"). Consider the past tense verb "ran" in 1b. A past tense verb requires the opposite relation between R and S from that established in 1a (ie., it requires time of reference precede time of speech (R<S)). Such a tense shift has serious consequences to the discourse organization. For, not only does a new time of reference need to be established, but, most likely, a new discourse segment as well (Grosz & Sidner, 1986).

Webber (1988) has proposed that discourse processing often proceeds along the "path of least resistance" (minimal inference). Readers and listeners will avoid costly discourse processing, such as segmentation, unless explicitly marked (as in 1b). Natural questions that arise from this processing perspective are: a) at what point in processing do listeners and readers consider tense in relation to temporal properties of the discourse, and b) can discourse constraints related to such considerations influence processing at a structural level.

To explore these questions, we made use of the well-known temporary ambiguity associated with restrictive reduced relative clauses. Ambiguous phrases such as "The student spotted..." can be continued either as a main clause with a past tense form of the verb (e.g., "The student spotted the proctor and went back to work") or a relative clause with a participial form of the verb (e.g., "The student spotted by the proctor received a warning"). Crucially, a past tense in a main clause and a participle in a relative clause require different temporal and event information to be present in the discourse. A past tense verb in a main clause requires time of reference to precede time of speech. However, participial verbs in relative clauses make no restrictions on R and S, because these phrases only refer to events already established in the discourse.

Much of the empirical work on the reading of reduced relative clauses has revealed that readers experience a large mis-analysis effect (or 'garden-path') in such sentences because the reader has initially interpreted the verb as a past tense verb in a main clause (Ferreira and Clifton, 1986; Trueswell et al, 1992). We explored whether this mis-analysis of relative clauses can be eliminated when the temporal constraints of a discourse do not easily permit a main clause past tense interpretation. Such a finding would demonstrate that readers process tense in relation to the temporal properties of the discourse, and that this temporal information can rapidly influence syntactic processing.

Method

Twenty University of Rochester students participated in the study. Eye movements of each subject were recorded using a Stanford Research Institute Dual Purkinje Eyetracker. The eyetracker transmitted information concerning horizontal and vertical eye position angle of the subject's right eye to a Macintosh II computer equipped with an analog to digital conversion board. Eye position was determined by sampling every millisecond both the horizontal and vertical eye angle and blink signals from the eyetracker. The position and duration of each fixation was computed and stored to disk. Stimuli were displayed on a high resolution RGB monitor, with the subject's eyes approximately 64 cm from the screen. The visual angle of each character was slightly greater than 12 minutes of arc, allowing for one character resolution from the eyetracker position signals. For each subject, the eyetracker was aligned and the signal was calibrated to the screen coordinates. Each trial consisted of the presentation of a three to five sentence paragraph. The subject read the sentences silently and then pressed a button to signal that he or she was finished. On about a third of the trials, a yes/no comprehension question appeared on the screen prior to the line trace test. Subjects were given feedback as to whether their button response answer was correct. (See Trueswell et al, 1992, for a more complete description of a similar procedure.)

An example target paragraph is shown in Table 1. The 16 target paragraphs were embedded in 44 distractor paragraphs containing various constructions, and various temporal relations. See Trueswell & Tanenhaus (1991) for a complete list and description of the target stimuli.

Table 1: Example of target stimuli.

Context	
Past	
Several students were sitting together taking an exam yesterday. A proctor came up and noticed one of the students cheating.	
Future	
Several students will be sitting together taking an exam tomorrow. A proctor will come up and notice one of the students cheating.	
Target	
Reduced:	
The student spotted by the proctor received/will receive a warning.	
Unreduced:	
The student who was spotted by the proctor received/will receive a warning.	

Predictions

The past context establishes the appropriate temporal parameters for a new past event to be introduced into the discourse, whereas the future context does not. Therefore, a fragment such as "The student spotted..." should be interpreted as part of a main clause in the past context and as part of a reduced relative clause in the future context. This prediction was confirmed in a sentence completion study (Trueswell & Tanenhaus, 1991). The present study was conducted to determine whether these temporal constraints would affect on-line processing.

Results

Total Reading times

Each target sentence was divided into three scoring regions: the initial noun phrase ("The student"), the relative clause ("spotted by the proctor"), and the verb phrase region ("will receive" or "received a"). Figure 1a presents mean total reading times for each region (the total amount of time spent within a region, including rereads of a region). To better see any effect of ambiguity, Figure 1b shows the difference in total reading times between ambiguous reduced relative clauses and unambiguous unreduced relative clauses for both future and past contexts. Positive differences reflect increased difficulty in processing a region when the relative clause did not contain the "who was" (ie., when it was reduced).

The temporal information in the discourse context clearly mediated the magnitude of the garden-path for sentences with reduced relative clauses. In past contexts, the (ambiguous) reduced relative clauses took longer to read than the (unambiguous) unreduced relative clauses. Such a result indicates that readers initially interpreted the first verb as a past tense verb in a main clause. The subsequent "by-phrase" signalled that the segment was in fact a relative clause, requiring a reanalysis. However, in the future contexts, reduced relatives took only slightly longer to read than the unreduced relatives.

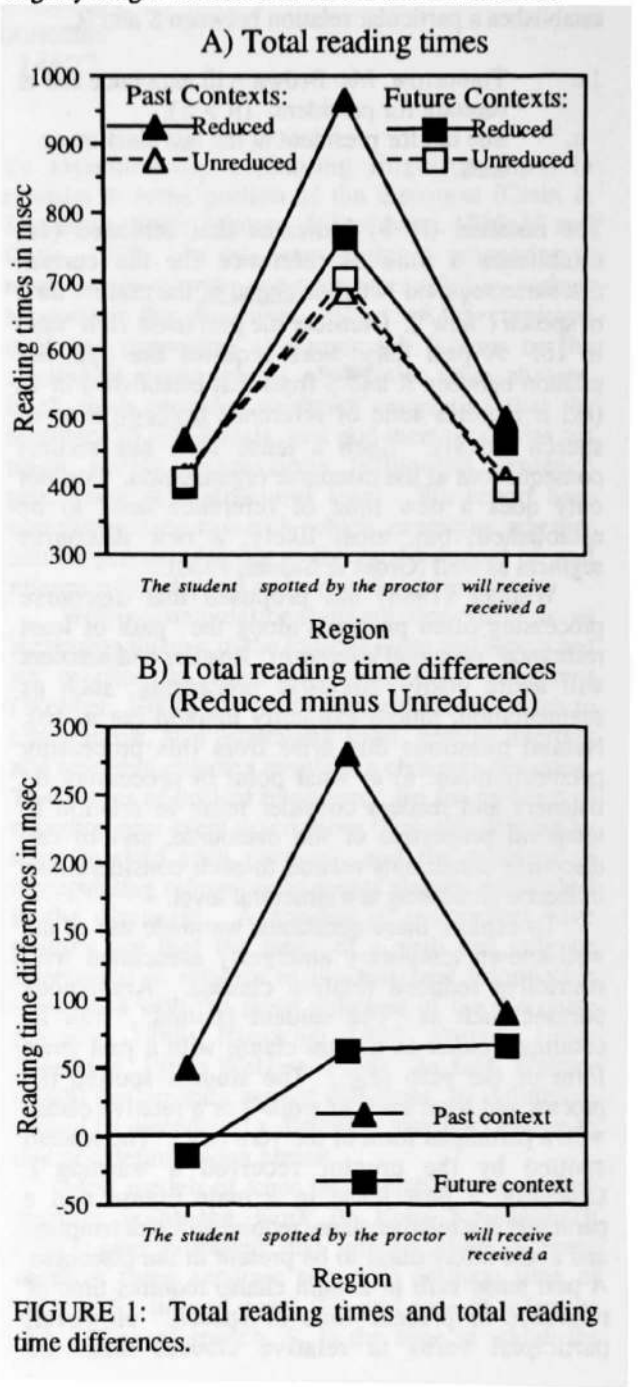

FIGURE 1: Total reading times and total reading time differences.

An analysis of variance was conducted on the data at each scoring region. At the initial noun phrase region, there were no reliable effects or interactions. At the relative clause region, however, there was a clear interaction between the type of clause (reduced and unreduced) and the type of context (future or past), $F_1(1,16)=10.87$, $MSe=22102$, $p<0.01$; $F_2(1,12)=4.88$, $MSe=31098$, $p<0.05$. In past contexts (triangles), subjects spent more time reading the reduced relative clauses as compared to unreduced relatives ($F_1(1,16)=48.11$, $MSe=16312$, $p<0.01$; $F_2(1,12)=10.40$, $MSe=57405$, $p<0.01$). In future contexts (squares), subjects took only slightly longer to read the reduced relatives as compared to unreduced relatives, and the difference was not reliable, $F_1(1,16)=1.64$, $F_2(1,12)=1.46$). Finally, at the verb phrase region, there was an effect of relative clause type, $F_1(1,16)=24.14$, $MSe=5759$, $p<0.01$; $F_2(1,12)=5.07$, $MSe=17015$, $p<0.05$.

First and Second pass reading times

Total reading times do not differentiate between initial processing and secondary processing (re-reads). To investigate better the time course of these effects, total reading times were separated into first pass and second pass reading times. First pass reading times were obtained by summing the durations of all left-to-right fixations in a region plus any regressions made to other points within that region. When the reader made an eye movement out of a region (either a regressive eye movement to a prior region or a forward movement to a following region), first pass reading was considered complete for that region. Second pass reading times include all re-readings of a region. It is commonly believed that first pass reading times reflect the processes associated with deriving an initial interpretation of a region whereas large second pass reading times reflect reanalyses caused by arriving at an incorrect initial interpretation.

The difference in reading times between the reduced and unreduced relative clauses for first and second pass readings are shown in Figures 2a and 2b respectively. Both the first and second pass data show the same pattern as the total reading times. There were large differences in reading times between the reduced and unreduced relative clauses in the past contexts, and only small unreliable differences in the future contexts. Moreover, all of the effects and interactions at the relative clause region that were significant in the total reading times were also reliable in the first pass ($p<0.05$). Such a result indicates that temporal information influenced ambiguity resolution early on in processing.

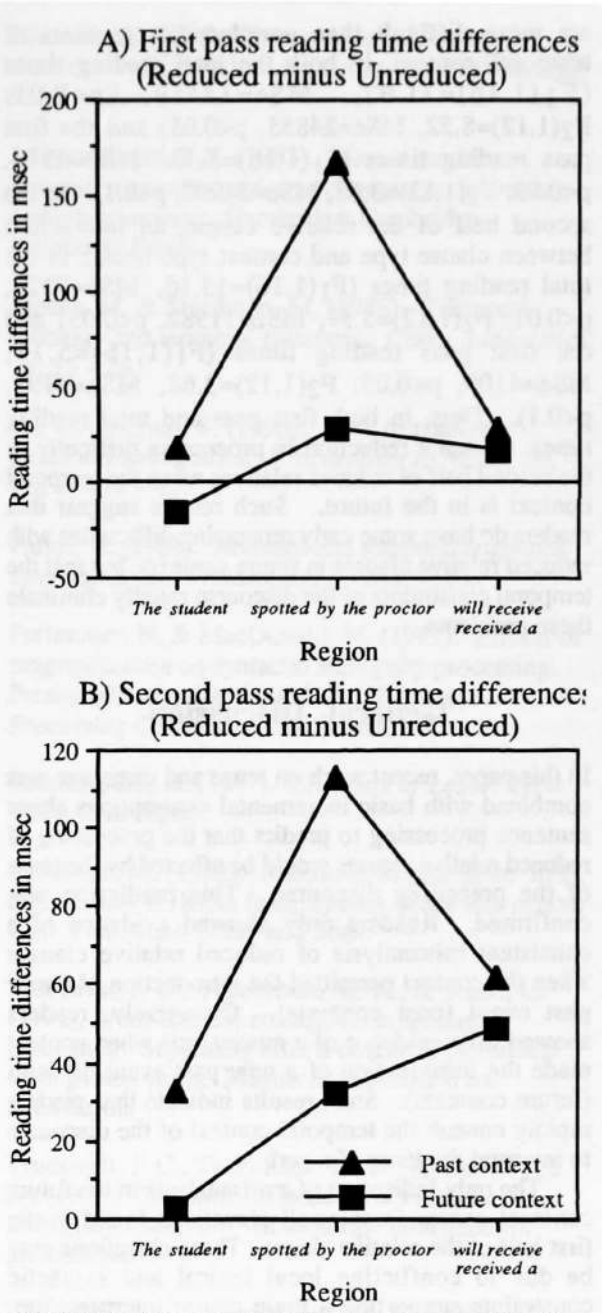

FIGURE 2: First pass and second pass reading time differences.

Dividing up the relative clause region

Finally, additional analyses were conducted in which the relative clause scoring region was divided into two smaller regions ("spotted by" and "the proctor"). Such a division provides a breakdown of relative clause processing into early and late processing of the clause. Figure 3a and 3b present reading time differences between reduced and unreduced relative clauses for both total and first pass reading times. In the first half of the relative clause, reduced relatives

are more difficult than unreduced, regardless of temporal context, in both the total reading times ($F_1(1,16)=21.92$, $MSe=13459$, $p<0.01$; $F_2(1,12)=8.52$, $MSe=24855$, $p<0.05$) and the first pass reading times ($F_1(1,16)=5.13$, $MSe=5217$, $p<0.05$; $F_2(1,12)=3.68$, $MSe=24990$, $p<0.1$). In the second half of the relative clause, an interaction between clause type and context type occurs in the total reading times ($F_1(1,16)=15.16$, $MSe=7128$, $p<0.01$; $F_2(1,12)=5.59$, $MSe=11582$, $p<0.05$) and the first pass reading times ($F_1(1,16)=5.11$, $MSe=4109$, $p<0.05$; $F_2(1,12)=3.68$, $MSe=4491$, $p<0.1$). Thus, in both first pass and total reading times, we see a reduction in processing difficulty in the second half of reduced relatives when the temporal context is in the future. Such results suggest that readers do have some early processing difficulties with reduced relative clauses in future contexts, but that the temporal constraints of the discourse rapidly eliminate these problems.

General Discussion

In this paper, recent work on tense and discourse was combined with basic incremental assumptions about 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. Readers only showed evidence of a consistent misanalysis of reduced relative clauses when the context permitted the introduction of a new past event (past contexts). Conversely, readers showed little evidence of a misanalysis when context made the introduction of a new past event difficult (future contexts). Such results indicate that readers rapidly consult the temporal context of the discourse to interpret the tense of a verb.

The only indication of a misanalysis in the future contexts comes from small elevations found in the first half of the relative clause. These elevations may be due to conflicting local lexical and syntactic constraints supporting a main clause interpretation. It is likely that the comprehension system is sensitive to the fact that most sentences beginning with a noun phrase followed by a verb are main clause active sentences (Bever, 1970). Moreover, the semantic information of the head noun phrase supports a main clause interpretation (e.g., "student" is an animate object and a likely Agent of "spotted") (Trueswell, Tanenhaus & Garnsey, 1992). It is possible that discourse constraints cannot immediately "veto" these cues, but rather the temporal constraints from the discourse can only combine rapidly with these other constraints to arrive quickly at a relative clause interpretation (e.g., via constraint satisfaction). In addition, some of this small effect may be due to some localized complexity

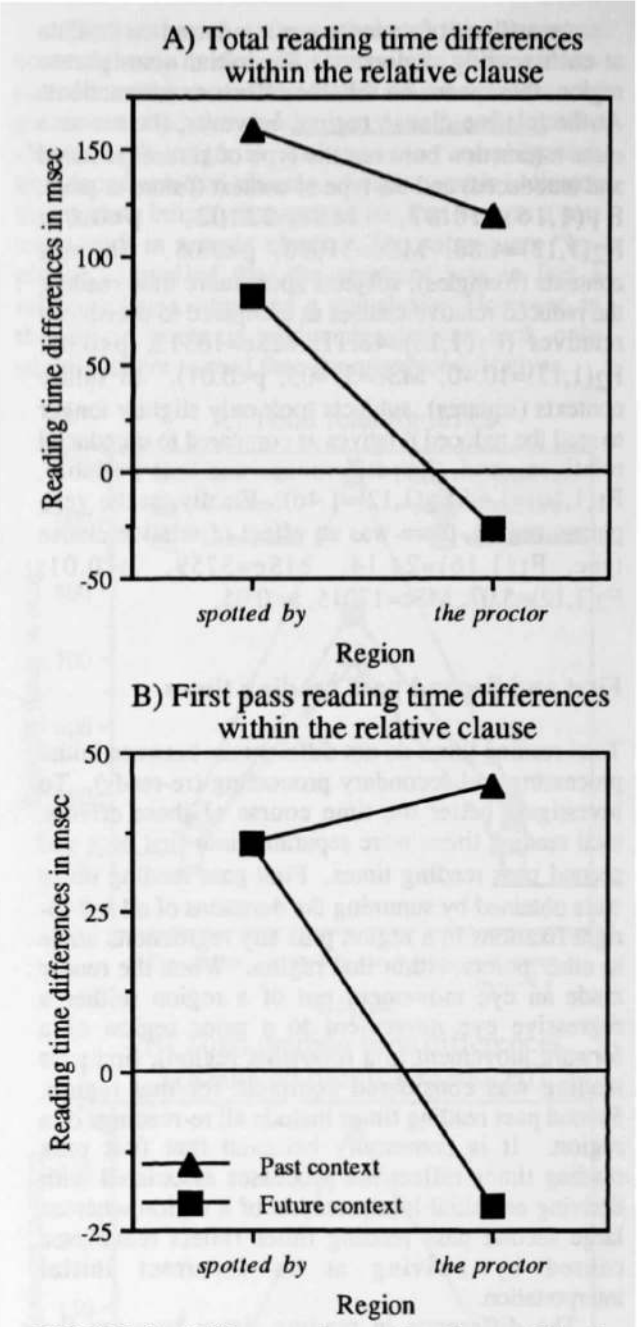

FIGURE 3: Differences in reading times within the relative clause for: a.) total reading times, and b.) first pass reading times.

difference between reduced and unreduced relatives, unrelated to ambiguity. Such an account has been offered elsewhere (Trueswell, Tanenhaus and Garnsey, 1992; Trueswell and Tanenhaus, 1991; Perlmutter and MacDonald, 1991). These complexity differences could be factored out by using morphologically unambiguous verbs as the base-line control (e.g., "The student seen by the proctor").

The present results, and those of Trueswell and Tanenhaus (1991), 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. An important question for future research will be to determine the extent to which other types of temporal information in the discourse model influence immediate sentence processing. It is possible that only temporal parameters such as time of reference and time of speech are consulted when a tense marked verb is encountered. Alternatively, readers may attempt more detailed updating in which the event denoted by a verb is related to other relevant events in the discourse. If this is the case, real-world knowledge about determining the temporal and causal relations 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).

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