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Temporal References and Temporal Relations in Sentence Comprehension

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The author investigated the interpretation of temporal references during comprehension of sentences containing a main and subordinate clause. Experiments 1 and 2 examined state and event subordinate clauses, respectively, and showed that subordinate temporal references overlapping with or close to the time of the main clause event were read faster than nonoverlapping distant references. Experiment 3 examined temporal references in nonsubordinate main clauses and confirmed that temporal relations between main and subordinate clauses were established on-line in the previous experiments. Experiment 4 independently manipulated temporal overlap and distance and suggested that event and state clauses are processed according to distinct temporal parameters. The results are explained by the contingency relations that events and states establish with other discourse events.

Time plays an important role in our cognitive representations. For example, perception of scene pictures depicting events are distorted by our knowledge of the events' dynamic properties (Finke, Freyd, & Shyi, 1986; Freyd, 1987; Kelly & Freyd, 1987); events described in narratives are represented in memory in chronological order, which may or may not be consistent with the order of mention in discourse (Anderson, Garrod, & Sanford, 1983; Carreiras, Carreido, Alonso, & Fernández, 1997; Mandler, 1986; Radvansky, Zwaan, Federico, & Franklin, 1998; van der Meer, Beyer, Heinze, & Badel, 2002; Zwaan, 1996); and events occurring at temporally contiguous times are more closely related in memory than are events occurring at distant times (Anderson et al., 1983; Carreiras et al., 1997; Radvansky et al., 1998; van der Meer, Beyer, Heinze, & Badel, 2002; Zwaan 1996). Such findings indicate that our mental representations of events include information about both the event's internal dynamics and its temporal location relative to others.

However, how do we actually get to build such complex representations? In particular, how do comprehenders establish temporal relations on-line and mentally locate events in time during the course of word-by-word comprehension? Numerous studies have investigated how comprehenders establish causal and temporal relations between events in the domain of discourse comprehension. These studies show that sentences introducing temporal and causal discontinuities into the narrative are read more slowly than sentences containing temporal and causal links to previous sentences (Anderson et al., 1983; Bloom, Fletcher, van den Broek, Reitz, & Shapiro, 1990; Fletcher, Hummel, & Marsolek, 1990; O'Brien & Myers, 1987; Zwaan, 1996; Zwaan, Magliano, & Graesser, 1995; Zwaan, Radvansky, Hilliard, & Curiel, 1998). For example, Zwaan (1996) investigated the effect of discourse time shifts such as *an hour later* in the context of a sequence of narrated events (e.g., *John was beaming. A moment later . . .*). Sentential reading times were longer after a large time shift such as *an hour later* than a short time shift such as *a moment later*. The author attributed this difference to the violation of the expected chronological and causal order of events and to the cost of introducing new situation models into the discourse representation. This sort of finding has led to the proposal that comprehenders monitor events' temporal and causal relations (among others) in narratives, that is, comprehenders construct a mental model of the situations described and the relationships between them (Zwaan & Radvansky, 1998; Zwaan et al., 1995; see also Graesser, Millis, & Zwaan, 1997, for a review).

Compared with the discourse literature, however, relatively few studies have investigated the on-line effect of establishing temporal relations at constituents smaller than the sentence when tense and temporal references themselves are processed and integrated into the current context. In one such study, Trueswell and Tanenhaus (1991) found that a tensed verb is immediately interpreted against the time of the previous event(s) established in discourse. The authors investigated whether the bias to initially interpret a past participle like *spotted* in a reduced relative clause as the main past verb of the sentence (e.g., *The student spotted . . . by the teacher stood up*) would be reduced in temporal contexts that were inconsistent with such a past-tense interpretation (as in *In tomorrow's exam, any student spotted by the teacher will be punished*). The comparison of sentences preceded by either past-tensed or future-tensed contexts indicated that reduced relative clauses were read faster in future contexts than in past contexts. The authors therefore argued that temporally locating information conveyed by the tense is immediately evaluated relative to the context in a way that facilitates the resolution of syntactic ambiguities.

In another study, Zwaan (1996) also suggested that time shifts in a narrative describing the protagonist's actions are quickly interpreted relative to the situation model constructed thus far in discourse. Zwaan reported that the temporal distance between events has immediate effects on processing temporal references: Temporally close time shifts (e.g., *an hour later*) are processed faster than relatively large time shifts (*a day later*). Zwaan argued that temporally contiguous time shifts in a narrative would involve

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fewer processing resources than distant temporal shifts because fewer changes to the current situation representation would be needed. Taken together, these two studies (Trueswell & Tanenhaus, 1991; Zwaan, 1996) indicate that temporal information is rapidly calculated on-line relative to the current mental model when time-referring expressions, such as tense and temporal adverbs, are encountered.

Along the lines of these studies, I investigated how comprehenders process temporal references relative to the current context as the sentence unfolds. Specifically, I examined subordinate constructions in which two distinct events are described—the main and the subordinate event. In *The news reported that Clinton visited Russia*, the main event is the report and the subordinate event is the visit. In such cases, the past tense of the embedded verb *visited* conveys the information that the time of the visit was before the time of the news report, that is, it establishes a precedence relation between the events. Other temporal references such as *yesterday* or *last week* modifying either event would further specify the exact temporal location of the event relative to the speech time and other discourse events, if any. In *The news reported yesterday that Clinton visited Russia last week*, the temporal references provide the calendar location of the events and thus imply that the events were about a week apart.

The question now arises when and how temporal relations and temporal locations are assigned to the events during the course of sentence interpretation, and more generally, what properties of the representation entertained on-line have consequences for processing. It is hypothesized, following proposals in semantics (Dowty, 1986; Gennari, 2003) that lexical semantic information interacts with causal and chronological knowledge of events in the world to generate different representations of events' temporal locations. Data supporting such a proposal would reveal the processing mechanisms underlying on-line temporal interpretation and more importantly, the architecture of the processor necessary to account for the complex interplay of various types of information. This area of research thus promises to illuminate the nature and interplay of the various constraints and processing mechanisms active during sentence interpretation along the lines of several previous studies (MacDonald, Pearlmutter, & Seidenberg, 1994; MacDonald, 1993; Spivey-Knowlton & Sedivy, 1995; Tanenhaus & Trueswell, 1995). Overall, the results reported below support an interactive view of processing in which properties of the event structure and its causal relations with other events determine how temporal locations are processed.

Event Structure, World Knowledge, and Temporal Interpretation

Several studies in temporal semantics (e.g., Dowty, 1986; Hinrichs, 1984; Kamp & Reyle, 1993; Moens & Steedman, 1988; Partee, 1984; Ter Meulen, 1995) have noted that the temporal interpretation of sentences depends on the causal structure of the events they describe, in particular, on whether an event or a state is involved. *Event denoting sentences* are those describing some change in the world: an agent acting or having some effect on another participant of the event, for example, somebody writing a letter or talking to a friend. *State denoting sentences*, in contrast, do not describe changes but rather properties of individuals or stable relations between participants, for example, someone deserving something, being sad, being tall, or loving someone (for the state–event distinction, see Dowty, 1979; Jackendoff, 1991; Parsons, 1990). This difference in the causal properties of the event denoted gives rise to radically different temporal interpretations.

Event-denoting sentences in the past tense tend to be temporally interpreted in sequence, that is, they either precede or follow some other event in discourse. In Example 1 below, the understanding is that the event of the second sentence occurs after the event of the first sentence. In contrast, state-denoting sentences tend to temporally overlap with previous discourse events, as shown in Example 2, in which the interval of the thesis being on the desk overlaps with Mary's going to see the advisor.

Example 1: Mary went to see her advisor this morning. They talked about her thesis.

Example 2: Mary went to see her advisor this morning. A copy of her thesis was on the desk.

The contrast also emerges in subordinate constructions, which are examined in this article. A subordinate event in past tense can only precede the main event. In Example 3 below, the time of the signing occurred earlier than the time of the main event. No other interpretation is possible. In contrast, state-denoting sentences tend to temporally overlap with the main event but also admit a precedence interpretation. In Example 4, the state of being sick most likely overlaps with the time at which the teacher reported this fact.

Example 3: The news reported that the president signed a commercial agreement with Mexico.

Example 4: The teacher said that the student was sick.

Example 5: The teacher said yesterday that the student was sick last week.

In Example 5, the being sick and the saying do not overlap. Rather, the interval in which the subordinate state is true precedes the teacher's saying time. According to intuitions and off-line judgments (Dickey, 2001), this possible interpretation is less available in the absence of the subordinate temporal reference as illustrated in Example 4. The contrast in temporal interpretation between event and state sentences is thus two-fold: They differ in the number of potential interpretations (one vs. two, respectively) and in the nature of the temporal relation they establish with other events (sequential vs. overlapping).

Several studies in temporal semantics (Dowty, 1986; Gennari, 2003; Kamp & Reyle, 1993; Moens & Steedman, 1988; Parsons, 2002; Ter Meulen, 1995) have argued that this contrast in interpretation is due to knowledge of the event's internal causal structure and the ways in which these structures typically relate to other events. Events in simple past tense tend to be interpreted in temporal sequence because they involve some sort of causal change. This change tends to establish causal and contingency dependencies with other events in discourse, often entailing and presupposing such dependencies, like the preconditions for or consequences of its happening (cf. Moens & Steedman, 1988; Kamp & Reyle, 1993). For instance, visiting a place (as in *Clinton visited Russia*) presupposes traveling to this location, and entails having been there. In Example 1 above, the talking is contingent on Mary's going to see the advisor. In subordinate constructions

such as that of Example 3, the mere occurrence of the main reporting event is contingent on the reported subordinate event having already occurred. All such contingency relations are inherently sequential. The causal structure of events and their implied causal and contingency dependencies thus preclude the availability of temporal overlap.

This situation radically contrasts with that of states in past tense. States do not have internal causal structure, do not entail consequences and can overlap with other events. In fact, an overlapping temporal interpretation is often preferred in subordinate constructions, as exemplified earlier. Dowty (1986) and Gennari (2003) explained this preference for overlap by arguing that the states' lack of causal structure entails the possibility of their continuation or persistence in time as long as the knowledge of the state in question permits (e.g., being sick or being tall). Dowty called this the principle of inertia (see also Lascarides & Asher 1993; Ter Meulen, 1995). Intuitively, if Mary was sick yesterday, the assumption is that she had been and would be sick for some period of time around yesterday, unless otherwise specified. In subordinate constructions, the persistence of the subordinate state for some typical duration implies an overlapping relation with the time of the main event (in Example 4, the student was sick around the time of the teacher's saying). In general, the ability to persist in time, combined with world knowledge of the state's typical duration, lead comprehenders to assume that states are more likely to overlap, rather than follow, other events in discourse. This assumption would explain the preference for overlapping interpretations in subordinate constructions, even though a precedence relation is in principle possible.

Assuming that these observations are correct, the question now is how and when, if at all, these properties of events and states come into play in the process of building a temporal interpretation on-line. Note that as the sentence unfolds during word-by-word reading, both event and state clauses display similar indeterminacies. For states, the subordinate tense does not specify when the subordinate state ends. In principle, the interval denoted by the state could end before the main event occurs (as in Example 5), or it could continue to be true as the main event occurs (as in Example 4). Similarly, although event subordinates unambiguously precede the main event in most cases, the tense does not indicate when exactly the subordinate event has finished relative to the time of the main event. For example, in Example 3, the signing of the agreement could have happened, say, a day or a week before the report. Thus, in both state and event subordinates, there is an indeterminacy as to how distant from the main event the subordinate clause will be, if at all. How comprehenders deal with this indeterminacy during the course of sentence comprehension is the main question addressed by the studies reported below. The hypothesis adopted here, along the lines of the temporal semantics studies mentioned above, is that event structure properties of states and events, as well as knowledge of the typical relations they establish with other events in discourse would guide comprehenders toward a particular temporal interpretation precisely when temporal indeterminacies are encountered.

To test this hypothesis, in Experiment 1, I investigated whether during the on-line interpretation of subordinate clauses, the persistence properties of states and their typical temporal relations lead comprehenders to assume an overlapping or preceding temporal interpretation relative to the main reporting event. This was accomplished by examining the reading times for temporal references conveying one or the other interpretation. Similarly, in Experiment 2, I investigated whether the causal properties of events and their typical temporal relations guide comprehenders to establish temporally close or distant relations relative to the main event, given that the tense leaves this information unspecified. This was also accomplished by examining the reading times for corresponding close and distant temporal references. Experiment 2 thus paralleled Experiment 1, replacing state with event subordinate clauses. In Experiment 3, I investigated, for both events and states, the contribution of the main event to the on-line process of temporal interpretation. This was to determine whether a relation with the main event is in fact computed on-line when the subordinate clause is processed. Finally, in Experiment 4, I investigated whether the temporal properties of subordinate states systematically lead to overlap interpretations or rather to any interpretation temporally close to the main event. Taken together, the experiments also addressed the general question of whether event and state clauses involve somewhat different underlying mechanisms. Such mechanisms are expected if differences in event structure properties and in the typical temporal relations they establish with other events have observable processing consequences.

Experiments

Experiment 1: Processing Temporal References in State Clauses

In Experiment 1, I investigated the nature of the temporal relation established on-line when comprehenders encounter the verb phrase of a subordinate state. As discussed in the introduction, the subordinate state in constructions such as *The teacher said that the student was sick* could in principle receive an overlapping or preceding interpretation relative to the main event. The question investigated here is whether the initial interpretation established at the subordinate verb phrase is one that overlaps with the time of the main verb or else is left unspecified until further information is provided or until postsentential inferences are computed.

The first of these alternatives follows from the theory outlined earlier according to which state verbs and phrases in general are assumed to persist in time and therefore are assumed to overlap with previously mentioned events. That is, along the lines of Trueswell and Tanenhaus (1991), when the subordinate verb phrase is encountered, the lexical and world knowledge provided by the phrase immediately causes the processor to establish an overlapping interpretation relative to the main event (the *immediate interpretation* alternative). The other alternative, having temporarily unspecified temporal relations, would be expected if the subordinate past tense is interpreted as temporarily ambiguous between the two possible readings (overlap vs. precedence) and left unspecified until further information is encountered (the *late interpretation* alternative). This sort of view has been proposed by Dickey (2001), who argued that temporal interpretation in nonsubordinate sentences is delayed until the processor finds the relevant temporal reference or more information about the event described.

These two alternatives thus make different predictions regarding the interpretation of time referring expressions occurring in a subordinate state. Consider the first example in Table 1, *A journalist confirmed today that population growth was stable this year/last year*, which illustrates the materials used in Experiment 1. The first version of the sentence contains a subordinate temporal

Table 1
Examples of Stimulus Items in Experiment 1

Example	Sentence	Condition
1a	A journalist confirmed *today* that population growth was stable *this year* despite	Overlap
1b	A journalist confirmed *today* that population growth was stable *last year* despite	Nonoverlap
2a	The minister admitted *two days ago* that diplomatic relations with Cuba were difficult *this year*	Overlap
2b	The minister admitted *two days ago* that diplomatic relations with Cuba were difficult *last month*	Nonoverlap

reference *this year*, which overlaps with the time of the main event *today* (the denotation of *today* is included in the denotation of *this year*). The second version contains *last year* as subordinate temporal reference, which does not overlap with the time of the main event *today*. Whereas the late interpretation alternative does not predict specific differences, the immediate interpretation alternative predicts a difference in reading times between these subordinate temporal references, because only the first one (*this year*) is consistent with the initial overlap assumption. According to the immediate interpretation hypothesis, at the point in which *was stable* is interpreted, an overlapping relation with *today* is established in the mental model. When the later temporal reference *this year* is encountered, the interval referred is consistent with the initial interpretation; thus, no particular difficulty is expected. However, when the reference *last year* is read, there must be a reinterpretation or reanalysis of the initial overlap relation into one in which the interval of being stable ends before the reporting time *today*. Therefore, the processing time associated with *last year* should be longer than that of *this year*, given the semantic reanalysis associated with the former, but not latter, phrase.

Method

Materials. Eighteen pairs of sentences such as those in Table 1 were constructed. All state-denoting sentences except for one contained the verb *be* plus an adjective, which referred to a state of affairs according with traditional classifications (Dowty, 1979). The members of each sentence pair were exactly alike except for the temporal reference applying to the subordinate clause. In the overlap condition, the subordinate temporal reference overlapped with the time of the main event. In the nonoverlap condition, the temporal reference did not overlap with the time of the main event, that is, its denotation did not include, but preceded, the time of the main event. Appendix A shows the stimuli used in this experiment with the temporal references highlighted.

In all cases except one, the temporal references modifying the subordinate clause consisted of a determiner such as *this* or *last* and a noun denoting a temporal interval, for example, *week, month, year, Thursday*. The frequency and number of letters of these nouns were matched (log frequency of overlapping condition = 5.27, nonoverlapping condition = 5.28, number of characters = 4.7 for both conditions, according to Collins Cobuild corpus). The corpus frequency of occurrence of the determiner and noun together (e.g., *this year* vs. *last year*) were also matched using the British National corpus (the mean frequency of co-occurrence across the overlapping expressions was 4,774 versus 4,669 for nonoverlapping expressions, $t < 1$). The frequency of the determiners themselves could not be matched because there were only two determiners used (*this, last*), both highly frequent words with a log frequency of 5.90 and 5.57, respectively.

The items were counterbalanced for temporal distance. Consider the examples in Table 1 again. The first example compares overlapping versus nonoverlapping references such as *this year* and *last year*. In this case, if one were to locate *last year* on a time line relative to the time of the main event *today*, *last year* would be located in a more distant position than *this year*. The second example however, compares *this year* with *last month* in the overlap and nonoverlap condition, respectively, in which the denotation of the nonoverlapping temporal reference *last month* would be effectively included within the denotation of the overlapping reference *this year*, and thus it would be located closer in time to the main event than *this year*. In this case, the overlapping reference extends farther away from the main event's time than the nonoverlapping phrase. Half the items in the stimuli followed the pattern of the first example in Table 1, whereas the remaining half followed the pattern of the second example. This ensures that if overlapping phrases are processed faster than nonoverlapping ones, it cannot be due to the fact that overlapping phrases are simply closer to the main event.

Design and procedure. Thirty undergraduates at the University of Maryland, College Park, participated in this study. The stimuli were presented together with the materials of Experiment 2 below embedded within 100 filler items of various syntactic forms (subordinate and nonsubordinate constructions). Each subject saw all 18 items, half in the overlap condition, half in the nonoverlap condition. Sentences were presented in a self-paced word-by-word reading paradigm. At the beginning of each trial, participants saw a left-justified line of dashes standing for the words of the sentences separated by spaces. As they pressed the space bar, each new word was displayed, and the word just read went back to dashes. Reading times for each word were recorded. After each sentence was read, there was a comprehension question. This question referred to the temporal references of the subordinate state in 12 of the 18 experimental cases (e.g., Was population growth stable this year?) to check that temporal information was in fact attended to. No temporal references were made for the filler items.

The time it took to read the temporal reference and in particular, the temporal noun (e.g., *week, month*) within the subordinate clause was the dependent variable of interest. Reading times longer than 1,000 ms were excluded from the analysis. This represented 1.6% of the data corresponding to all experimental items of Experiments 1 and 2.

Results

The proportion of correct responses to the comprehension questions for the overlap versus the nonoverlap conditions was .80 and .85, respectively. Paired *t* test revealed that the two conditions did not differ significantly ($p > 1$). Only sentences that were answered correctly were included in the analysis of reading times.

Analyses of reading times were performed over the four-word region corresponding to the subordinate temporal references such as *last week* or *this week* plus the preceding and following words. Mean reading times for these positions are shown in Figure 1. A repeated-measures analysis of variance (ANOVA) with reading times as the dependent variable and Word Position (previous word, determiner, noun, following word) and Temporal Overlap (overlapping vs. nonoverlapping temporal references) as main factors revealed a main effect of Temporal Overlap, $F_1(1, 29) = 6.7$, $MSE = 12{,}599$, $p = .02$; $F_2(1, 17) = 5.14$, $MSE = 16{,}186$, $p = .04$, with no interaction and no main effect of Word Position. Planned comparisons within word positions revealed a significant effect of overlap at the noun position (e.g., *week*), $F_1(1, 29) = 6.6$, $MSE = 13{,}447$, $p = .01$; $F_2(1, 17) = 4.90$, $MSE = 9{,}363$, $p = .04$. The mean reading time of the overlap condition at the noun position was 355 ms, whereas the mean reading time of the nonoverlap condition was 388 ms. No other significant difference was found.

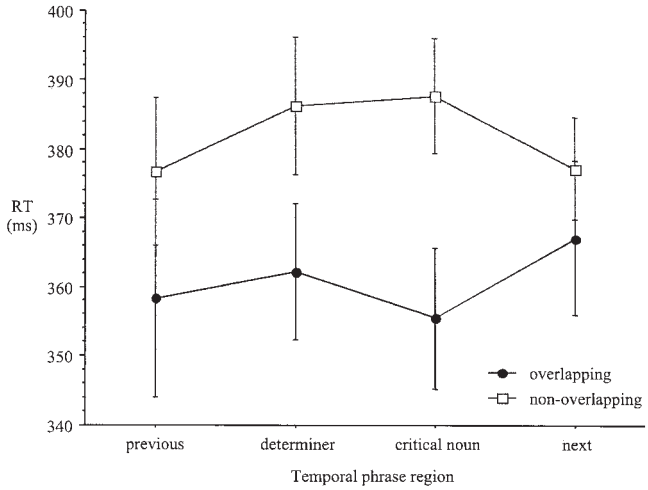

Figure 1. Reading times (RT) for the temporal phrase region of Experiment 1 as a function of temporal overlap and word position. Error bars indicate standard error.

The results suggest that temporal references overlapping the main event are easier to process than nonoverlapping ones. This is consistent with the hypothesis that at the time the verb phrase is processed, comprehenders establish an overlapping relation with the main event. Thus, more processing cost is observed for nonoverlapping phrases inconsistent with the initial interpretation.

Discussion

The results of Experiment 1 suggest that comprehenders make early commitments locating the subordinate state in time. Such commitments have observable processing consequences for time-referring expressions encountered further along in the sentence. It was hypothesized in the introduction that these commitments might take place, because the meaning of the subordinate state phrase (e.g., *be sick, be stable, be difficult*) implies that the state persists in time for some typical duration and that, therefore, it is most likely to overlap with other events previously mentioned. If correct, this possibility suggests that comprehenders quickly activate the world knowledge necessary both to represent the temporal duration of the subordinate state and to establish a temporal relation with the main event.

One question that emerges from this finding concerns its generalizability. The results of Experiment 1 suggest that there are processing consequences of establishing temporal relations on-line. Are such processing consequences also observable in contexts with other interpretation indeterminacies, as with subordinate events? As discussed in the introduction, state and event clauses both present temporary indeterminacies with respect to their temporal interpretation. The past tense of subordinate states admits two possible interpretations (overlapping or preceding). The past tense of subordinate events, in turn, although unambiguously indicating a precedence relation with the main event, does not specify how long before the main event the subordinate event occurred, that is, whether the subordinate event occurred in the recent or distant past. Do such indeterminacies also have observable processing consequences? To evaluate this possibility, in Experiment 2 I investigated the temporal interpretation of event subordinates.

Experiment 2: Processing Temporal References in Event Clauses

In event clauses, the subordinate tense unambiguously indicates that the event temporally precedes the main event. In *The news reported that Clinton visited Russia*, the temporal relation with the main event is not problematic. Thus, unlike subordinate states, comprehenders need not guess one temporal relation or another on the basis of likelihood or world knowledge. However, the tense does not indicate how long before the main event the subordinate event had happened, unless subordinate temporal references such as *last week* are provided. If, as suggested in Experiment 1, comprehenders compute temporal relations on-line when temporal references are encountered, and moreover, comprehenders use knowledge of the event structure and its typical relations to other events, it is possible that this sort of knowledge also leads the processor to differentially process close and distant temporal references in event subordinates. In Experiment 2, I investigated this possibility, in particular, whether temporal references temporally close to the main event's time are processed faster than distant temporal references.

To understand why distant versus close temporal references may involve different processing costs, recall from the introduction, that the temporal interpretation of events involves world knowledge of the causal and contingency dependencies that events are likely to establish with other events. This knowledge may be used to build a representation of the events' temporal relation on-line. Thus, larger distances between events may involve more complex causal and contingency relations between them, with greater consequent processing cost. Several discourse studies support such a hypothesis. Reading time effects of establishing causal and temporal relations have already been shown in the discourse literature (e.g., Bloom et al., 1990; Fletcher et al., 1990; O'Brien & Myers, 1987; Zwaan et al., 1995; Zwaan et al., 1998). These studies have provided evidence suggesting that sentences introducing causal and temporal discontinuities in narrative texts, which imply more temporal distance between events, take longer to read than connected sentences. Thus, if comprehenders use their knowledge of the situations described, as suggested by Experiment 1, and establish causal and contingency relations between the main and the subordinate event (as suggested in the discourse literature), they may find it easier to introduce a close temporal location into the discourse model rather than a distant one, because fewer changes in the situation (contingency) model built thus far would be required.

Consider, for instance, the examples in Table 2. Because the subordinate event temporally precedes the main event, comprehenders may attempt to establish a temporal and causal link from the subordinate event leading up to the main event. In Example 1a, comprehenders may think that for the police officer to inform the parents about the student's attacks, something must have occurred that led from the attack to the informing event, say, police were called up and conducted an investigation. Typical knowledge associated with the described situation provides the relevant information to establish a temporal–causal relation. Thus, encountering a subordinate temporal reference such as *last week* may not be too costly, either because this temporal location is within the typically

Table 2
Example of Stimulus Items in Experiment 2

Example	Sentence	Condition
1a	A police officer informed parents *yesterday* that a student attacked several classmates *last week*	Close
1b	A police officer informed parents *yesterday* that a student attacked several classmates *last month*	Distant
2a	The magazine revealed *this week* that a policeman shot a man *on Monday*	Close
2b	The magazine revealed *this week* that a policeman shot a man *last week*	Distant

expected sequence of events between the main and subordinate events, or because there is a small temporal gap between the two events to be interpreted in terms of contingencies. However, more distant temporal references may be more costly, either because they are less consistent with the initially hypothesized sequence of events, or because distant locations introduce more distance to be interpreted in terms of contingencies. To accommodate distant locations into the current model of the events, more intervening events would need to be conjured up (e.g., a longer police investigation before the public announcement), with a consequent processing cost.

Method

Materials. Sixteen pairs of sentences like those in Table 2 were constructed. All subordinate sentences contained event verbs describing some change in the world (e.g., *arrest, expel, visit*) and were classified as event verbs according to linguistic criteria (Dowty, 1979). One version of each pair contained a temporal reference that was temporally close to the time of the main event (the *close condition*), whereas the other version contained a more distant event (the *distant condition*). The nouns of these phrases were matched for frequency using the Collins Cobuild corpus (close condition: 5.28, distant condition: 5.47) and word length (close condition: 4.6, far condition: 4.5). The determiner preceding the nouns was always the same for the two conditions. Appendix B shows the stimuli of this experiment. Note that the difference in temporal distance between the close and distant condition was always relative to the item pair in question. For example, in some items, *last month* in the subordinate clause served as the *close* reference relative to the distant reference *last year*, but it served as the *distant* reference in other items relative to the closer reference *last week*.

Design and procedure. Design, participants, and procedure were as in Experiment 1. The time it took to read the temporal reference, and in particular, the temporal noun (e.g., *week, month*) within the subordinate clause was the dependent variable of interest.

Results

The proportion of correct responses to the comprehension question was .82 for the close condition and .80 for the distant condition, which were not reliably different from one another. In the analysis of reading times, a repeated-measures ANOVA was performed with Word Position (preceding word, determiner, noun, and following word) and Temporal Distance (close vs. distant) as main factors. This analysis revealed a significant interaction between these two factors, $F_1(3, 87) = 2.46$, $MSE = 3{,}478$, $p = .06$; $F_2(3, 45) = 2.88$, $MSE = 2{,}059$, $p = .04$. Results are displayed in Figure 2. Further planned comparisons within each word position revealed that at the noun position, the close and distant conditions differed significantly, $F_1(1, 29) = 9$, $MSE = 17{,}631$, $p = .005$; $F_2(1, 15) = 6.18$, $MSE = 9{,}422$, $p = .03$. No other comparison was significant. The mean reading time of the noun in the close condition was 339 ms, whereas in the distant condition it was 373 ms (see Figure 2). Thus, references that locate an event at a distant temporal location from the main event took longer to read than references that locate an event more closely.

Discussion

The results of Experiment 2 revealed that differential processing time associated with temporal references is independent of the presence of a potential ambiguity. Unlike state subordinates, event subordinates are not potentially ambiguous between two temporal interpretations, and yet, processing temporal references varied with temporal distance. Large temporal distances between the main and the subordinate event generated longer reading times than short distances, presumably because more causal and contingency dependencies (or a long event sequence) would need to be introduced into the situation model. Taken together, Experiments 1 and 2 suggest that the time it takes to integrate a temporal reference into the current interpretation of the sentence is modulated by the causal and temporal properties of the situation being built. Subordinate state clauses are quickly assumed to overlap with the main event because their ability to persist in time would lead comprehenders to expect an overlapping interpretation with the main event. Subordinate events, which unambiguously precede the main event, show a preference for close rather than distant temporal relations with the main event because of the causal and contingency dependencies established on-line on the basis of general world knowledge. These findings are thus consistent with the hypothesis that the lexical semantic properties of the subordinate verb (whether it denotes a state or an event) together with its associated world knowledge would give rise to different representations for each event type.

To strengthen the validity of these results, a critical question remains to be addressed, namely, whether the differences in read-

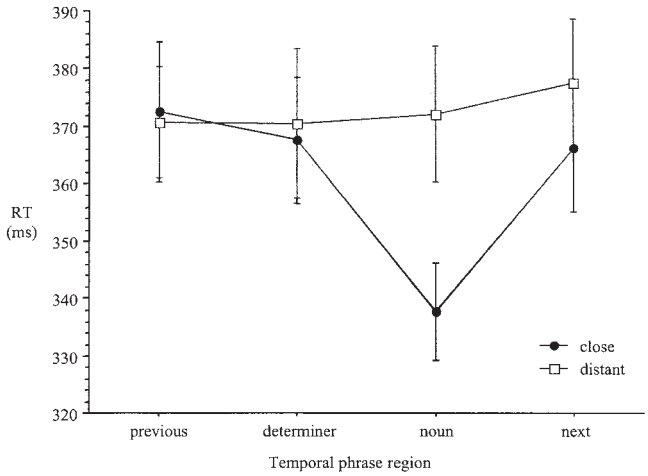

Figure 2. Reading times (RT) for the temporal phrase region of Experiment 2 as a function of temporal distance and word position. Error bars indicate standard error.

ing times observed are in fact due to the properties of the situation model being constructed, as hypothesized. Note that the interpretation of the findings of Experiments 1 and 2 relies on the assumption that comprehenders were actually establishing a temporal or causal relation between the main and subordinate event on-line. For this reason, the reading times of subordinate temporal references were taken to reflect the cost of integrating these references relative to the time of the main event. However, to conclusively demonstrate this point, one would need to show that introducing the same temporal references in a different sentential context, for example, in a nonsubordinate sentence, does not yield parallel reading time differences. This contention was investigated in Experiment 3. In doing so, the experiment also addressed other alternative explanations of the results of Experiments 1 and 2, for example, one in which the lexical properties of the words used, such as word frequency or lexical complexity, are responsible for the effects.

Experiment 3: Processing Temporal References in Nonsubordinate State and Event Sentences

In Experiment 3, I investigated whether the processing of temporal references in nonsubordinate sentences would yield similar results to those of Experiments 1 and 2. The purpose was to exclude alternative explanations for the effects found in Experiments 1 and 2. If the temporal references used in these experiments yield similar effects when occurring in nonsubordinate sentences, then the cost of processing them in Experiments 1 and 2 did not depend on establishing a temporal or causal relation with the main event, as hypothesized. Rather, the effect would have to be attributed to independent factors such as the frequency or the lexical meaning of the words involved.

Example sentences in this experiment for each state and event are provided in Table 3, in which the main verb of the previous materials was removed from the sentence. Note that as comprehenders read Examples 1 and 2, the tensed verb indicates that the state or event occurred at some past time before the time of producing the sentence. When comprehenders reach the temporal references, they locate this past event more precisely within the week or month preceding or including the production time. Unlike subordinate constructions, no temporal or causal relation needs to be established in the mental model between two distinct events described in the sentence. Thus, if the effects of Experiments 1 and 2 are due to the establishment of a temporal relation between the main and subordinate event, the reading times associated with temporal references such as those in Table 3 should not differ.

Table 3
Examples of Stimulus Items in Experiment 3

Example	Sentence	Event type	Condition
1a	Diplomatic relations with Cuba were difficult *this year*	State	Overlap
1b	Diplomatic relations with Cuba were difficult *last year*	State	Nonoverlap
2a	A student attacked several classmates *last week*	Event	Close
2b	A student attacked several classmates *last month*	Event	Distant

Method

Materials. Materials in this experiment were the same as those in Experiments 1 and 2 except that the main event was removed from the items, as shown in Table 3. A few changes were performed in some sentences to make them plausible and natural nonsubordinate sentences. Six more items, two pairs of state clauses, and four event clauses were added to increase power and were similar to the other items in all relevant respects. Thus, there were 20 event pairs like Example 2 in Table 3 and 20 state pairs like Example 1 in Table 3. Each pair contained the temporal references of the previous experiments and was labeled accordingly. For event sentences, one version of the item pair was called the *close condition*, whereas the other version was the *distant condition*. For state sentences, one version was called the *overlap condition*, as before, and the other version was the *nonoverlap condition*.

Design and procedure. Thirty English native speakers participated in this study, all students at the University of Maryland, College Park. Stimuli were presented within a set of 90 filler sentences of varying syntactic structures. Procedure and design were as in Experiments 1 and 2. Participants either saw the first or the second version of each state or event pair. Seventy-five percent of the comprehension questions accompanying the test stimuli included a temporal reference (e.g., *Were relations with Cuba difficult this year?*). As before, reading times longer than 1,000 ms were not included in the analysis. This set represented less than 2% of the temporal data.

Results

Proportion of correct responses to the comprehension questions were similar to those of Experiments 1 and 2. In state sentences with overlapping and nonoverlapping temporal references, the proportions of correct responses were .81 and .83, respectively. Similarly, the proportion of correct responses was .80 for event sentence with close temporal reference, whereas it was .82 for sentences with distant temporal references. There was no significant difference between these conditions.

Reading times were analyzed independently for event and state sentences. For state sentences, a repeated-measures ANOVA with Word Position (previous word, determiner, noun and next word of the adverbial region) and Temporal Overlap (overlap, nonoverlap) as independent factors and reading times for words as dependent variable revealed a main effect of Word Position, $F_1(29, 3) = 6.5$, $MSE = 1{,}1021$, $p = .0005$; $F_2(19, 3) = 19.1$, $MSE = 9{,}366$, $p < .0001$, no significant effect of Temporal Overlap and no interaction. Results are displayed in Figure 3, left panel. The word position effect was due to overall differences between positions (the previous word took longer to read than the last word of the region). Further planned comparisons revealed no significant differences between the overlap and nonoverlap conditions at all word positions, most notably at the noun position ($t < 1$). The statistical power of this comparison was calculated using the effect size from Experiment 1, according to Cohen's (1988) procedure for paired comparisons. For the item analysis, power was .73 and for the subject analysis, it was .82.

For event sentences, a repeated-measures ANOVA with Word Position (previous word, determiner, noun, and next word of the adverbial region) and Temporal Distance (close, distant) as independent factors and reading times as dependent variables revealed a main effect of Word Position, $F_2(19, 3) = 11.2$, $MSE = 18{,}338$, $p = .0001$; $F_1(29, 3) = 8.5$, $MSE = 20{,}952$, $p = .0001$, no effect of Temporal Distance, and no interaction. Results are shown in Figure 3 (right panel). Further planned comparison within word

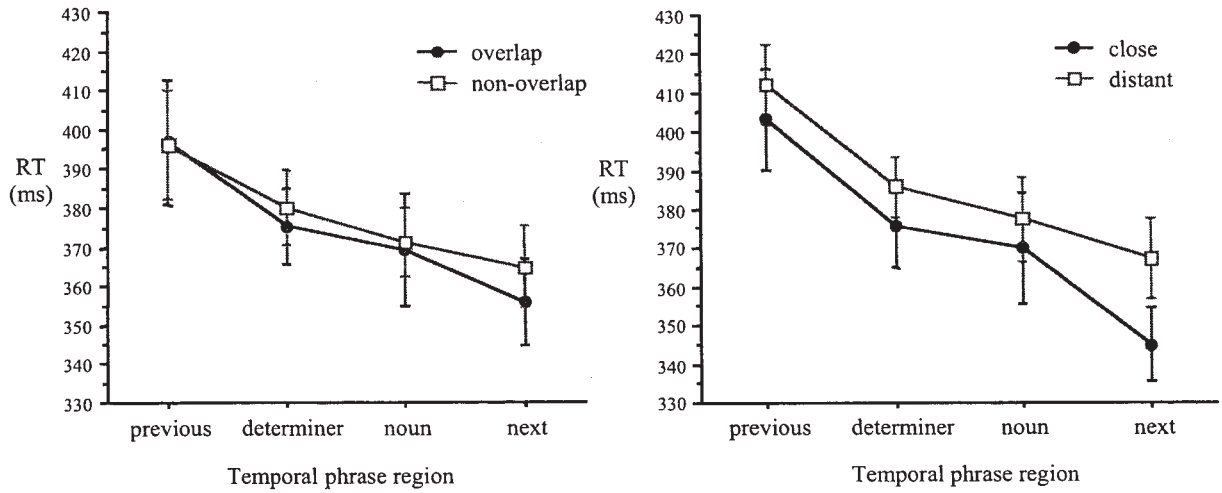

Figure 3. Reading times (RT) for the temporal phrase regions of Experiment 3. The left panel displays reading times for state clauses as a function of temporal overlap and word position. The right panel displays reading times for event clauses as a function of temporal distance and word position. Error bars indicate standard error.

position revealed no significant difference between close and distant conditions, particularly at the noun position ($t < 1$). Using the effect size of Experiment 2 for the power calculation, as in the previous analysis, the power of this comparison was .84 in both subject and item analyses.

Discussion

The results of Experiment 3 indicated that temporal references like those of Experiments 1 and 2 do not differ in their processing cost when used in nonsubordinate sentences. This implies that the effects of Experiments 1 and 2 were not due to properties of the temporal references themselves such as their lexical meaning or their frequency. More importantly, the results of Experiments 1, 2, and 3 together suggest that the presence of the main sentential verb is critical. The processing cost of subordinate temporal references derives from establishing a temporal relation between the main and the subordinate event on-line (precedence or overlap) as well as locating them in time relative to each other (distant or close). Time referring expressions thus show differential reading times depending on the properties of the sentential contexts and thus the mental model in which they are introduced.

One question that remains to be addressed is whether the mental models constructed for state and event clauses do in fact differ from one another according to the causal properties of their denotations. It was hypothesized that states' temporal persistence and the consequent implication of overlap with other events influenced the interpretation of state subordinates, whereas causal and contingency relations between events influenced the interpretation of event clauses. However, the overlap effect found for state subordinates could also be explained in terms of temporal distance, rather than overlap: Overlapping temporal references are necessarily closer in time than nonoverlapping references. To substantiate the current interpretation of the results, one would have to show that temporal distance is not the only factor accounting for all the reading times, for example, because of a general preference for contiguous rather than distant temporal locations in all cases (as proposed in Zwaan, 1996). If temporal distance was the only factor explaining the current results, it would be much harder to argue that the temporal persistence associated with states is responsible for the overlap interpretation, because in this case, temporal distance alone would account for all the results, with overlapping references being just another case of temporal contiguity. Moreover, it would be difficult to argue, as done so far, that the effect of temporal distance represents the cost of computing causal and contingency relations between events, because the interpretation of state clauses does not typically involve establishing such relations. Experiment 4 was designed to investigate this possibility.

Experiment 4: Temporal Distance and Temporal Overlap in State Clauses

In Experiment 4, I investigated whether the cost of integrating temporal references in subordinate states is also influenced by temporal distance beyond temporal overlap. Recall that in Experiment 2, distance was expressed by the temporal gap between two events, that is, the time elapsed between a reporting event *yesterday* and a subordinate event *last month* or *last year*. In Experiment 1, the temporal references only differed in whether they overlapped with the main event (e.g., *this week* vs. *last week* in the subordinate event relative to *yesterday* in the main event). These stimuli therefore did not include the proper temporal references to test for temporal distance independently of overlap, that is, a comparison between, say, *last week* and *last year* in the subordinate, as in Experiment 2. It is thus possible that overlapping references in Experiment 1 served as close references compared with distant nonoverlapping ones and therefore, that a preference for temporal contiguity explains both event and state clauses, regardless of the temporal–causal properties of the type of event denoted (event vs. state).

To investigate the effect of distance operating independently from overlap, conditions like those exemplified in Table 4 were compared, in which temporal overlap and temporal distant relative to the main event were crossed. For example, for a main event happening yesterday, an overlapping–close reference in the sub-

Table 4
Example of Stimulus Item in Experiment 4

Initial sentence context	Temporal reference	Condition
A new study reported yesterday that the president's approval rating was high	*this week*	Overlap–close
	this year	Overlap–distant
	last week	Nonoverlap–close
	last year	Nonoverlap–distant

ordinate clause was *this week*, an overlapping–distant reference was *this year*, a nonoverlapping–close reference was *last week*, and a nonoverlapping–distant reference was *last year*. Note that the comparison equivalent to Experiment 2 would be that between the nonoverlap–close and nonoverlap–distant conditions. Note also that the comparison between the overlap–close and overlap–distant conditions captures differences in the size of the overlapping intervals (e.g., *this week* vs. *this year*, in which *week* denotes a shorter interval than *year*). Comparisons across all conditions may reveal whether the overlap versus nonoverlap effect interacts with or depends on distance in any of its forms (interval size or temporal gap). If there is simply an overlap effect as found in Experiment 1, overlapping times should be faster than nonoverlapping times, regardless of interval size (e.g., *this week–this year* taken together should be faster than *last week–last year* together). Moreover, if there is an effect of distance independently of overlap, either the nonoverlapping or overlapping close conditions should differ from the corresponding distant conditions (i.e., *last week* should be faster than *last year* or *this week* should be faster than *this year*). Finally, if the cost of integrating a temporal reference is a function of both the overlap assumption and the temporal distance to be calculated, one would expect an interaction in which *this year* is slower than *this week* but faster than *last week* and *last year*.

Method

Materials. Twenty sets of sentences like those in Table 4 were prepared, each containing the four relevant conditions. The sentences contained as many different adverbs as could occur in English in such constructions (e.g., *week, year, season, quarter, term, century*). The stimuli are listed in Appendix C. Note that the temporal nouns of both close overlap and nonoverlap conditions were the same in the stimuli (e.g., *this week–last week*), and only close versus distant temporal nouns varied (e.g., *this–last week* vs. *this–last year*). These varying nouns across conditions were matched for word length (4.66 vs. 4.76 character length) and frequency according to the Cobuild corpus (5.26 and 5.43 mean log frequency for close and distant words, respectively). As in Experiment 1, the only difference between the overlap versus nonoverlap conditions was in the determiners *this–last.*

Design and procedure. Participants were 43 undergraduates at the University of Maryland, College Park, and 24 undergraduates at the University of Wisconsin. All participants were paid or received course credit for participating. Participants saw all four conditions but only one token of each item. The procedure was as in Experiment 1. The dependent measure was reading times to the critical temporal noun. Reading times longer than 1,000 ms were excluded from the analysis, as in the previous experiments.

Results

The proportion of correct responses for the comprehension questions did not differ across conditions (overlap–close condition = .86, overlap–distant = .84, nonoverlap–distant and nonoverlap–close = .88). A repeated-measures ANOVA with reading time to the subordinate temporal noun and Temporal Overlap (overlap vs. nonoverlap) and Temporal Distance (close vs. distant) as factors revealed a main effect of Temporal Overlap, $F_1(1, 65) = 5.08$, $MSE = 16{,}216$, $p = .03$; $F_2(1, 19) = 5.77$, $MSE = 6{,}386$, $p = .02$, no main effect of Temporal Distance and no interaction. The overlapping conditions were about 18 ms faster than the nonoverlapping conditions. Figure 4 shows the overlap and the distant effect plotted across different word positions of the subordinate temporal phrase region. Planned comparisons indicated that close and distant overlapping times (*this week, this year)* did not differ significantly. Moreover, close and distant nonoverlapping times (*last week* vs. *last year*) had nearly identical mean reading times (348 and 349 ms). To check that the overlap effect was only found at the critical noun position, similar repeated-measures ANOVAs were performed on the reading time of the words

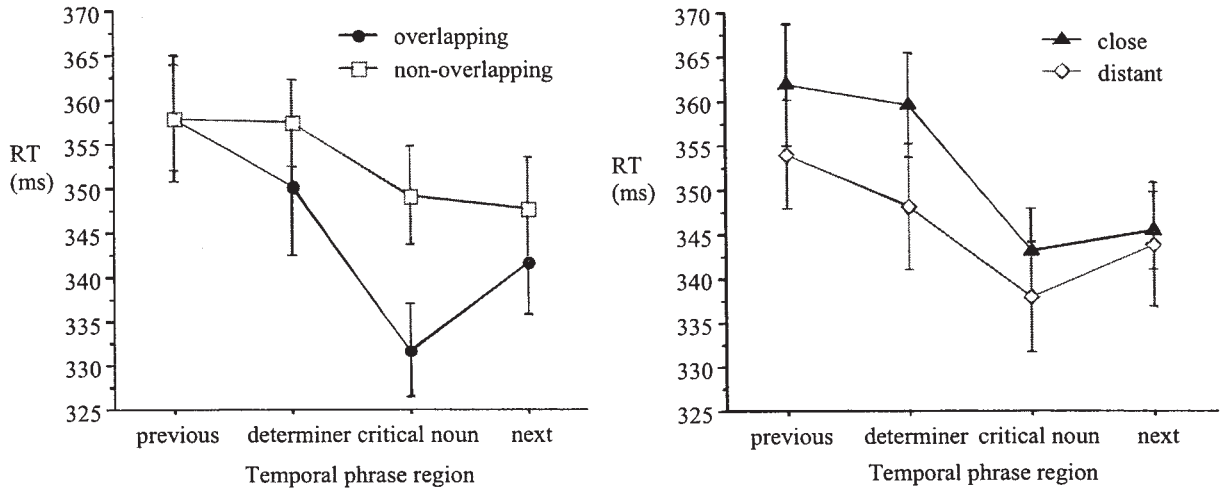

Figure 4. Reading times (RT) for the temporal phrase region of Experiment 4 as a function of temporal overlap, temporal distance, and word position. The left panel displays the overlap main effect. The right panel displays the distance effect. Error bars indicate standard error.

preceding and following the critical noun (at the determiner and the next word after the temporal noun) and revealed no interaction and no main effects.

The results indicated that subordinate state clauses are initially interpreted as overlapping the time of the main event, with little or no extra cost added when the size of the overlapping interval is large (*this year* is not more costly than *this month*). Moreover, although overall nonoverlapping phrases are more costly than overlapping ones, there was no distance effect for nonoverlapping temporal references (*last year* vs. *last week*), suggesting that when reanalysis of the initial overlap interpretation applies, it is equally costly to accommodate a nonoverlapping close or a distant temporal reference into the interpretation being built.

Discussion

The results of Experiment 4 confirmed the results of Experiment 1. There was a tendency to interpret the subordinate state as overlapping the main event. Also, there was no distance effect in all possible comparisons: Neither the size of the introduced overlapping interval nor the temporal gap between subordinate and main references had an effect on reading times. This radically contrasts with the results of Experiment 2, in which there was a clear distance effect. This contrast indicates that (a) a general expectation of temporal contiguity is not operative with state clauses, and (b) temporal distance is only relevant for the interpretation of event clauses. This is consistent with the interpretation provided for the distance and overlap effects of Experiments 1 and 2. With state clauses, temporal persistence leads to an overlap interpretation with the main event early in the subordinate clause, thus making later overlapping references easier to integrate. In contrast, the interpretation of events is guided by typical causal and contingency relations between the main and the subordinate event, making temporal distance a critical factor for generating differential reading times. Overall, the results suggest that the properties of the mental model constructed for each event type differ in pertinent temporal and causal properties and thus generate diverging processing consequences.

General Discussion

Summary of Results

In the experiments reported here, I investigated the process of establishing temporal references and temporal relations online. Experiment 1 showed that subordinate state clauses, which are potentially ambiguous between two interpretations (overlap vs. nonoverlap with the main event), tend to be interpreted as overlapping the main event. This was manifested by longer reading times when temporal references inconsistent with the initial interpretation were encountered. In Experiment 2, I investigated the processing of subordinate event clauses, which are constrained to precede the main event. It was shown that temporal references close to the main event are processed faster than distant references. In Experiment 3, I investigated nonsubordinate sentences with similar temporal references, as in Experiments 1 and 2, and found no differences in processing time. This was taken to indicate that the computation of the temporal relation between subordinate and main event is critical to yield differential processing times. Finally, in Experiment 4, I investigated whether temporal distance also affects the interpretation of subordinate states, in addition to overlap. There was no distance effect independent of overlap. Overall, the results indicated that the on-line temporal interpretation of state and event clauses were independently modulated by temporal overlap and temporal distance.

Interpreting Temporal References and Temporal Relations

The processing of state subordinate clauses differs from that of event subordinate in that they do not show a general preference for references close to the main event, as event subordinates do, but only a preference for overlapping temporal relations. This contrast suggests that event and state subordinate clauses may involve different ways of establishing temporal relations and assigning temporal locations on-line. For state subordinates, comprehenders establish an overlapping temporal relation with the main event early in the subordinate clause because they know that the subordinate state can persist for some typical interval and is therefore likely to overlap with other events in discourse. As a result, later temporal references inconsistent with this early interpretation trigger a revision of the temporal relation with the main event and take longer to integrate. Thus, the changes required in the current model to accommodate the incoming temporal reference are a function of revising the temporal relation between the main and subordinate clause. In contrast, events are unambiguously interpreted to precede the main event; thus, this aspect of the temporal structure constructed on-line (the chronological temporal sequence of events) need not be revised when temporal references are encountered. The interpretation indeterminacy of event subordinates only involves the exact temporal location of the subordinate event, that is, establishing by how long the subordinate event precedes the main event, because there are multiple possibilities. As a consequence, interpreting the relationship between the subordinate and the main event is a function of the causal and temporal distance between the events, activating the relevant world knowledge on-line to locate the events in time and construct a model of their causal relation.

The fact that state and event clauses differ in their interpretation mechanisms and in the temporal parameters they are sensitive to (overlap vs. distance) is claimed to derive from the internal causal structure of each event type and the nature of the contingency relations they establish with other events in discourse. States denote facts in the world, describing stable relations or characterizing properties of entities. Thus, they do not describe cause–effect relations (e.g., killing, writing) and therefore do not directly entail consequences (e.g., somebody being dead, something being written). For this reason, they need not be interpreted as the immediate consequence or the cause of other events mentioned in discourse, particularly in subordinate constructions, although such interpretations are possible in discourse contexts if general world knowledge so dictates (e.g., *Jean was hungry, she decided to eat*). In subordinate constructions such as *A journalist confirmed today that population growth was stable this year–last year despite the influx of immigrants*, the subordinate state (the population growth itself) does not cause or trigger the (journalist's) informing event. Most likely, this event was triggered by the relevance of this piece of information for potential listeners and for the current topic.

In contrast, events denote causal changes that entail and presuppose relations with other events, such as the preconditions for or consequences of their happening (cf. Kamp & Reyle, 1993; Moens

& Steedman, 1988). When an event is introduced into the discourse model, comprehenders tend to establish these contingency dependencies with previous events (Bloom et al., 1990; Fletcher et al. 1990; O'Brien & Myers, 1987; Zwaan et al., 1998). In subordinate constructions, comprehenders build an interpretation in which the subordinate event causally leads to the occurrence of the main event, providing in effect an explanation for why the reporting event came to occur. In an event subordinate such as *A police officer informed parents today that a student attacked several classmates last week–last month*, the reported piece of information is not only relevant to potential addressees, as state clauses are, but also provides an explanation for how the officer's report came about. Unlike states, one can suppose a chain of causally related events beginning with the attacks that led to the involvement of the officer in informing the parents.

Thus, the nature of the rhetorical relationship that the subordinate state or event establishes with the main reporting event is responsible for the differential effect of temporal distance in each case. When somebody reports a particular fact, the implication is that this fact is mentioned because it is somehow relevant to the general purpose or topic of the discourse (it fits the goals of the speaker or hearer). However, the fact itself need not have any particular consequence that is causally connected with the report. More importantly, this relevance or topic relation between the subordinate and the main event need not change as a function of temporal distance. Whether the population growth was stable last year or last semester, the relevance relation with the main event of reporting this fact can be the same. This explains why the processing cost of nonoverlapping temporal references (e.g., *last month* vs. *last year*) does not increase with temporal distance. In state subordinates, no radical changes or representation of complex causal relations are required in the current contingency model to recover from the initial overlap interpretation. Subordinate events, in contrast, establish causal and contingency chaining relations with main reporting events on the basis of world knowledge, giving rise to greater interpretative efforts as a function of temporal distance.

This possible interpretation of the results is consistent with previous psycholinguistic findings in the domain of narrative interpretation. Many studies have reported that sentences that break the causal and temporal sequence of events take longer to read (Bloom et al., 1990; Fletcher et al., 1990; O'Brien & Myers, 1987; Zwaan et al., 1995; Zwaan et al., 1998). For example, Zwaan (1996) reported a temporal distance effect on reading times and attributed it to the cost of integrating events that violate the chronological (causal) sequence of events. Moreover, reading times for sentences with no close causal antecedent in the narrative either take longer to integrate than those causally linked to the narrated sequences of events (Bloom et al., 1990; Fletcher et al., 1990; O'Brien & Myers, 1987) or trigger the reinstantiation of clauses earlier in the narrative if these clauses describe a cause of the event currently being described (Klin & Myers, 1993). These findings indicate that comprehenders attempt to establish causal and temporal relations between events in a narrative and that the absence of clear contingency links between events has observable processing consequences. Thus, this suggests that similar relations may be represented in subordinate constructions with similar processing consequences when key temporal references are introduced into the current situation model. In the absence of a narrative scenario, however, searching for relevant information in the previous discourse does not occur. Instead, default scenarios must be activated from long-term memory to aid interpretation.

In sum, the on-line processing of event and state subordinate clauses presents different characteristics. For state clauses, an overlapping temporal relation with the main event is initially established in the representation of the situation described but is later reanalyzed when a nonoverlapping temporal reference is encountered. Recovering from this initial interpretation involves reinterpreting the temporal relation with the main event but does not involve a computation of a new causal or contingency relation. In contrast, the on-line interpretation of event subordinates does not involve reinterpreting or revising the temporal relation initially established with the main event but does involve making changes to the contingency relation between the events when distant temporal references are processed. In both cases, the cost of processing the subordinate temporal reference is a function of the changes required in the current situation model to accommodate the new reference. They differ, however, in the nature of the changes required: a revision of the temporal relation in one case, the accommodation of a short or long dependency in the other. Overall, the results suggest that the causal and temporal properties of the unfolding situation being built determine the integration cost of new upcoming temporal information.

Event Structure and World Knowledge

The findings of this work have important implications for understanding how comprehenders achieve the interpretation of sentences, and more generally, for the interaction of different sources of information entertained on-line. On the one hand, the event structure conveyed by the lexical meaning (whether it is a state or an event) is immediately processed with respect to the temporal and contingencies relations established relative to the main event. Event structure is thus central in sentence interpretation (cf. Gennari & Poeppel, 2003). On the other hand, the information accessed is not only lexical in nature but also derived from general world knowledge associated with the event described. This suggests a rapid integration of semantic information, rather than temporarily unresolved interpretations, and a close (perhaps indistinguishable) relation between the verbs' lexical meaning and the world knowledge associated with it (cf. Ferretti, McRae, & Hatherell, 2001; McRae, Ferretti, & Amyote, 1997): The interpretation mechanism quickly processes the temporal properties of the event together with their likely causal and temporal relations.

The role of world knowledge and lexical meaning is particularly relevant because the syntactic information alone, particularly the tense morphology, is not specific enough to provide the proper interpretation (both overlap and precedence relations are possible with subordinate past tense). The picture that emerges from these observations is that the process of building semantic interpretations on-line involves representing aspects of the event structures denoted and their world contingencies. This is consistent with a probabilistic constraint approach to sentence processing (MacDonald, 1993; MacDonald et al., 1994; Tanenhaus & Trueswell, 1995) according to which the semantic and syntactic analyses that are entertained on-line depend on the probabilistic strength of the cues to those analyses as the sentence unfolds. In temporarily ambiguous situations such as that of subordinate states, the cues to an interpretation come from the typical duration of the denoted state and thus, the probability of its relation to the main event. In

temporary interpretation indeterminacies like those of event subordinates, the interpretation process is sensitive to contingency relations between events in the world, hence, the distance effect. In either case, the process of building a semantic representation of the situation described seems to involve probabilistic knowledge of the world, both at the level of the event denoted (e.g., its typical event structure and duration) and at the level of the relationship between more or less distant events. This adds to the probabilistic constraint approach important details about the nature of the constraints operating in sentence processing, and particularly, on semantic interpretation, independently of parsing decisions. Event structure and causal world knowledge are the major force driving semantic interpretation and are as likely to drive the processor as other currently known constraints. Studying how these factors interact during sentence comprehension is an important part of understanding how sentence comprehension works.

References

Anderson, A., Garrod, S. C., & Sanford, A. J. (1983). The accessibility of pronominal antecedents as a function of episode shifts in narrative texts. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 35*(A), 427–440.

Bloom, C. P., Fletcher, C. R., van den Broek, P. W., Reitz, L., & Shapiro, B. P. (1990). An on-line assessment of causal reasoning during comprehension. *Memory & Cognition, 18,* 65–71.

Carreiras, M., Carreido, N., Alonso, M. A., & Fernández, A. (1997). The role of verb tense and verb aspect in the foregrounding of information during reading. *Memory & Cognition, 25,* 438–446.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. San Diego, CA: Academic Press.

Dickey, M. W. (2001). *The processing of tense*. Dordrecht, the Netherlands: Kluwer Academic Publisher.

Dowty, D. (1979). *Word meaning and Montague grammar*. Dordrecht, the Netherlands: Kluwer Academic.

Dowty, D. (1986). The effects of aspectual class on the temporal structure of discourse: Semantics or pragmatics? *Linguistics and Philosophy, 9,* 37–61.

Ferretti, T. R., McRae, K., & Hatherell, A. (2001). Integrating verbs, situation schemas, and thematic role. *Journal of Memory and Language, 44,* 516–547.

Finke, R. A., Freyd, J. J., & Shyi, G. C. (1986). Implied velocity and acceleration induce transformations of visual memory. *Journal of Experimental Psychology: General, 115,* 175–188.

Fletcher, C. R., Hummel, J. E., & Marsolek, C. J. (1990). Causality and the allocation of attention during comprehension. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 233–240.

Freyd, J. J. (1987). Dynamic mental representations. *Psychological Review, 94,* 427–438.

Gennari, S. P. (2003). Tense meanings and temporal interpretation. *Journal of Semantics, 20,* 35–71.

Gennari, S. P., & Poeppel, D. (2003). Processing correlates of lexical semantic complexity. *Cognition, 89,* B27–B41.

Graesser, A. C., Millis, K. K., & Zwaan, R. A. (1997). Discourse comprehension. *Annual Review of Psychology, 48,* 163–189.

Hinrichs, E. (1984). Temporal anaphora in discourse of English. *Linguistics and Philosophy, 7,* 63–83.

Jackendoff, R. (1991). Parts and boundaries. *Cognition, 41,* 9–45.

Kamp, H., & Reyle, U. (1993). *From discourse to logic: Introduction to model theoretic semantics of natural language, formal logic and discourse representation theory*. Dordrecht, the Netherlands: Kluwer Academic.

Kelly, M. H., & Freyd, J. J. (1987). Explorations of representational momentum. *Cognitive Psychology, 19,* 369–401.

Klin, C. M., & Myers, J. L. (1993). Reinstatement of causal information during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 554–560.

Lascarides, A., & Asher, N. (1993). Temporal interpretation, discourse relations and common sense entailments. *Linguistics and Philosophy, 16,* 437–493.

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

MacDonald, M. C., Pearlmutter, N., & Seidenberg, M. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review, 101,* 676–703.

Mandler, J. M. (1986). On the comprehension of temporal order. *Language and Cognitive Processes, 1,* 309–320.

McRae, K., Ferretti, T. R., & Amyote, L. A. (1997). Thematic roles as verb-specific concepts. *Language and Cognitive Processes, 12,* 137–176.

Moens, M., & Steedman, M. (1988). Temporal ontology and temporal reference. *Computational Linguistics, 14,* 15–28.

O'Brien, E. J., & Myers, J. L. (1987). On the role of causal connections in the retrieval of text. *Memory and Cognition, 15,* 419–427.

Parsons, T. (1990). *Events in the semantics of English: A study in subatomic semantics*. Cambridge, MA: MIT Press.

Parsons, T. (2002). Eventualities and narrative progression. *Linguistics and Philosophy, 25,* 681–699.

Partee, B. H. (1984). Temporal and nominal anaphora. *Linguistics and Philosophy, 7,* 243–286.

Radvansky, G. A., Zwaan, R. A., Federico, T., & Franklin, N. (1998). Retrieval from temporally organized situation models. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 1224–1237.

Spivey-Knowlton, M., & Sedivy, J. C. (1995). Resolving attachment ambiguities with multiple constraints. *Cognition, 55,* 227–267.

Tanenhaus, M. K., & Trueswell, J. C. (1995). Sentence comprehension. In J. Miller & P. Eimas (Eds.), *Speech, language and communication* (pp. 217–262). San Diego, CA: Academic Press.

Ter Meulen, A.G. B. (1995). *Representing time in natural language. The dynamic interpretation of tense and aspect*. Cambridge, MA: MIT Press.

Trueswell, J. C., & Tanenhaus, M. K. (1991). Tense, temporal context, and syntactic ambiguity resolution. *Language and Cognitive Processes, 6,* 303–338.

van der Meer, E., Beyer, R., Heinze, B., & Badel, I. (2002). Temporal order relations in language comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 770–779.

Zwaan, R. A. (1996). Processing narrative times shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1196–1207.

Zwaan, R. A., Magliano, J. P., & Graesser, A. C. (1995). Dimensions of situation model construction in narrative comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 386–397.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123,* 162–182.

Zwaan, R. A., Radvansky, G. A., Hilliard, A. E., & Curiel, J. M. (1998). Constructing multidimensional situation models during reading. *Scientific Studies of Reading, 2,* 199–220.

Appendix A

Sentence Stimuli of Experiment 1

1. The teacher denied *today* that the absentee students were out of town *this week/last week* and decided not to excuse them.
2. The newspaper reported *yesterday* that public opinion was favorable to war *this month/last week* despite the fear of terrorism.
3. The old secretary lamented *today* that her husband was angry at her *this morning/last Thursday* because she worked late last night.
4. Professor Hobbes complained *this week* that the department secretary was very busy *this semester/last Wednesday* and she could not help him with his grant.
5. Some religious reformers believed *in 1600* that there was a perfect society *then/once* somewhere on earth.
6. The presidential candidate pointed out *this week* that interest rates were high *this month/last week* despite the government's efforts.
7. A journalist confirmed *today* that population growth was stable *this year/last year* despite the influx of immigrants.
8. The Chinese delegate announced *today* that there were no religious demonstrations *this month/last week* after the government concessions.
9. John's mother thought *yesterday* that his grades were good *this week/last week* because he had studied more seriously.
10. The minister admitted *two days ago* that diplomatic relations with Cuba were difficult *this year/last month* after the declared embargo.
11. Union representatives complained *this week* that the unemployment rate was alarming *this month/last month* and requested government intervention.
12. Professor Smith said *today* that his students hated his classes *this month/last week* when he talked about trigonometry.
13. The teenager told his friend *yesterday* that his girlfriend was a cheerleader *this year/last year* so they went to all the games.
14. The scouts agreed *this week* that their meetings were boring *this month/last week* because of low attendance.
15. Jane wrote *yesterday* that she was in London *this month/last winter* and the weather was fine.
16. An officer revealed *today* that a famous thief was in prison *this year/last month* after his network was dismantled.
17. The carpenter thought *today* that a coworker was unfair to him *this week/last week* after they had a dispute.
18. The vice-president agreed *this week* that Congress was inefficient *this year/last year* because of partisan disagreements.

Note. Temporal references used in the experiment are shown in italics. The first temporal reference was used in the overlapping condition. The second reference was used in the nonoverlapping condition.

Appendix B

Sentence Stimuli of Experiment 2

1. The police confirmed *on Monday* that they arrested several drug dealers *last week/last month* as they flew in from Mexico.
2. The Israeli government disclosed *today* that its officers expelled several foreigners *last week/last month* after intense investigations.
3. The president confirmed *this evening* that his officials visited the Russian Embassy *this morning/on Monday* to obtain its diplomatic support.
4. The Mayor admitted *today* that he threatened a congressman earlier *this month/this year* and he was summoned for it.
5. A police officer informed parents *yesterday* that a student attacked several classmates *last week/last month* after silly disputes.
6. Human Rights organizations announced *this morning* that a policeman killed a woman *last night/last week* after a demonstration.
7. A congressman denied *today* that the state of Texas executed an innocent person *last month/last year* without a fair trial.
8. The bartender told his friend *this morning* that a woman stabbed a man *last night/one night* while they were dancing.
9. The Professor confirmed *on Tuesday* that his technician stole chemicals from the lab *last week/one day* and then disappeared.
10. The department chair complained *today* that the dean decided on a new professor earlier *this week/this year* without his consent.
11. The manager admitted *this week* that the advisers rejected his proposal *last week/last month* because of its environmental implications.
12. The press confirmed *today* that a judge gave a speech in the Senate *last week/last month* to discuss the Justice Department.
13. The magazine revealed *this week* that a policeman shot a man *on Monday/last week* after a fierce fight.
14. *Yesterday,* it was revealed that the actress rejected the director's offer earlier *this week/this year* because she does not like working with him.
15. The governor commented *today* on why he fired his entire staff *last week/last month* after the press accusations.
16. An American company made public *this week* that it bought a Canadian firm *last month/last year* for one million dollars.

Note. Temporal references used in the experiment are shown in italics. The first temporal reference was used in the close condition. The second reference was used in the distant condition.

(*Appendixes continue*)

Appendix C

Sentence Stimuli of Experiment 3

1. In yesterday's meeting, a teacher complained that many students were out of town *this week/this month/last week/last month* because of the basketball games.
2. A new study reported yesterday that the president's approval rating was fairly high *this month/this year/last month/last year* because of the fear of terrorism.
3. The personnel manager argued at a meeting yesterday that employees' productivity was poor *this month/this year/last month/last year* because they had been bombarded with many different responsibilities.
4. The professor regretted today that his teaching assistant was unable to attend classes *this week/this term/last week/last term* because she missed several important topics.
5. The school superintendent said this afternoon that the young teacher was clearly overwhelmed *this term/this year/last term/last year* but that she will get better.
6. The presidential candidate deplored at an interview today that interest rates were inadequate *this month/this quarter/last month/last quarter* and affected businesses.
7. A recently published study showed that New York's population growth was remarkably stable *this decade/this century/last quarter/last century* despite the increasing influx of immigrants.
8. A freelance journalist confirmed today that Israeli authorities had secret meetings with Arafat *this week/this month/last week/last month* after the Israeli police arrested several suspects.
9. The young undergraduate admitted on Monday that his math grades were quite unsatisfactory *this term/this year/last term/last year* because he had not understood trigonometry.
10. The defense minister admitted this week that diplomatic relations with Cuba were difficult *this month/this year/last month/last year* after the declared embargo.
11. The steel workers reminded their union yesterday that the unemployment rate was elevated *this month/this year/last month/last year* and expected them to take proper action.
12. The logic teacher told a colleague yesterday that some students hated her seminar *this week/this term/last week/last term* because she talked about Godel's theorem.
13. The basketball player told a friend today that his girlfriend was a cheerleader *this term/this year/last term/last year* and they went to all the games for free.
14. A news report revealed this week that presidential candidates had less campaign contributions *this month/this year/last month/last year* because of the new law prohibiting corporate donations.
15. The business traveler wrote to his friends today that he was in Afghanistan *this week/this month/last week/last month* and that security was not a problem for moving around the country.
16. The Colombian police confirmed yesterday that the most wanted drug dealer was missing *this week/this month/last week/last month* after his headquarters were dismantled.
17. The Californian carpenter reminded his manager on Tuesday that he deserved a bonus *this month/this season/last month/last season* because he worked hard to meet the deadlines.
18. Many political analysts agreed on Tuesday's show that the budget committee was inefficient *this year/this season/last year/last season* because of partisan disagreements.
19. The main directors were happy today that the company's advertising strategies were successful *this month/this season/last month/last season* and that sales climbed up.
20. Senator Clark announced yesterday that bankrupt farmers and small businesses needed public loans *this month/this season/last month/last season* in order to reactivate the entire economy.

Note. Italics indicate the temporal references used in each condition. The first phrase corresponds to the overlap–close condition, the second phrase corresponds to the overlap–distant condition, the third phrase corresponds to the nonoverlap–close condition, and the fourth phrase corresponds to the nonoverlap–distant condition.

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