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Use of Verb Information in Syntactic Parsing: Evidence From Eye Movements and Word-by-Word Self-Paced Reading

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We investigated whether readers use verb information to aid in their initial parsing of temporarily ambiguous sentences. In the first experiment, subjects' eye movements were recorded. In the second and third experiments, subjects read sentences by using a noncumulative and cumulative word-by-word self-paced paradigm, respectively. The results of the first two experiments supported Frazier and Rayner's (1982) garden-path model of sentence comprehension: Verb information did not influence the initial operation of the parser. The third experiment indicated that the cumulative version of the self-paced paradigm is not appropriate for studying on-line parsing. We conclude that verb information is not used by the parser to modify its initial parsing strategies, although it may be used to guide subsequent reanalysis.

In reading, it is not sufficient that words be identified. Words must also be combined into a coherent structure that indicates their interrelationships. For example, in Sentence 1,

1. Mary said Bill left yesterday,

it is important to establish whether the word *yesterday* is to be grouped with the verb *said* (Mary made the statement yesterday and Bill left at some unspecified time) or whether *yesterday* is to be grouped with *left* (Mary conveyed the information that Bill left yesterday). The structure in which such grouping information is conveyed is a syntactic structure, which indicates the hierarchical relationships among words. For Sentence 1, the two interpretations are associated with two different structures. We will refer to the process of assigning a syntactic structure to a sentence as *parsing*.

Frazier and her colleagues (Frazier, 1978, 1987; Frazier & Fodor, 1978; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983; Rayner & Frazier, 1987) have proposed that words are organized into a syntactic structure as they are encountered and that only a single structure is initially computed for a sentence. Consider Sentence Fragment 2:

2. Mary suspected the man. . . .

The phrase *the man* is ambiguous because it could be either the direct object of *suspected* or the subject of an embedded clause, as illustrated in Sentence 3.

3. a. Mary suspected the man from Calgary.
   b. Mary suspected the man had committed the crime.

According to Frazier's model, the parser will initially commit itself to the direct object analysis of *the man* because it is syntactically simpler, a strategy Frazier terms the *minimal attachment principle*. If the sentence continues as in #3b, the parser is *garden-pathed*: It initially constructs the wrong analysis (is led down the garden path) and therefore must reanalyze the sentence.

Frazier and Rayner (1982) monitored readers' eye movements and found that the fixation durations on sentences such as #3 were indistinguishable in the *a* and *b* versions in the region *Mary suspected the man* and then increased on the next word in the *b* version. The word *had* was associated with longer fixation times in the *b* version because it disambiguated the syntactic analysis towards a less preferred alternative. The minimal attachment principle, then, states that words are assigned the syntactically simplest analysis, and only if the analysis turns out to be incorrect does the parser compute a second, more complex structure.

Minimal attachment has been found to operate independently of both within-sentence semantic information (Rayner et al., 1983) and between-sentence discourse context (Ferreira & Clifton, 1986). The question to be addressed in this article is this: Does information about the syntactic properties of the main verb affect parsing strategies? For example, consider Sentence 4.

4. John realized the road was closed.

The main verb *realized* is rarely followed by a direct object (*Bill realized the road yesterday). Minimal attachment stipulates that *the road* will be analyzed as a direct object, but the verb *realize* strongly prefers not to take one. A parser that could use verb subcategorization information (information

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about the kinds of phrases with which a particular verb can co-occur) could avoid making costly errors because a minimal attachment analysis of a direct object after a verb such as *realize* is almost certain to be incorrect.[1]

According to the Frazier and Rayner (1982) garden-path parsing model, subcategorization information is not initially used by the parser. In other theories, however, verb information is fundamental to the parser's operation. For example, Ford, Bresnan, and Kaplan's (1982) parsing model is based on the assumption that alternative syntactic structures are selected on the basis of the syntactic biases of the verb. For the sentences in #5,

5. a. John saw the girl was cheating.
   b. John realized the girl was cheating.

the girl is ambiguous when first encountered between a direct object and a subject-of-embedded-clause interpretation. According to Ford et al., the parser resolves the ambiguity by selecting the alternative consistent with the verb's biases. Verbs such as *saw* tend to be followed more often by direct objects than by sentence complements; verbs such as *realize* behave in an opposite manner. Ford et al. predicts for these two sentences that garden-pathing would occur only in Sentence 5a because only there does the ultimate form of the sentence violate the verb's expectations.

In contrast, the garden-path model predicts equal amounts of garden-pathing for both types of verbs. The minimal attachment strategy leads the parser to construct a direct object analysis of the phrase *the girl*, and only upon reaching the verb *was* does the parser detect its error. Syntactic structures are constructed by using only phrase structure rules, and the rules are context free. Subcategorization information is ignored during initial syntactic construction.

We will call the view that subcategorization information is used in initial parsing the *verb guidance hypothesis*. Mitchell and Holmes (1985) examined sentences involving a wide variety of ambiguities and found results consistent with this hypothesis. For example, a sentence such as *The historian suspected the manuscript of his book had been lost* took subjects less time to read than the same sentence with *read* as the main verb. Reading times for the phrase *had been lost* were 157 ms shorter when associated with main verbs such as *suspected*. These verbs more frequently occur with a sentence complement than do verbs like *read*.

Mitchell and Holmes employed a task in which subjects read phrase-sized segments one at a time in a self-paced fashion. This task may be too crude to tap into processes occurring when sentences are initially syntactically analyzed. The garden-path theory claims that sentences *initially* receive the simplest syntactic analysis possible. It is clear, however, that the simplest analysis is not always correct, and incorrect analyses must be revised. As argued by Mitchell in a later article (1990), it may be that sentences containing a verb consistent with the nonminimal analysis take less time to read in a phrase-by-phrase reading paradigm because the parser can more easily revise an initially incorrect analysis. In other words, phrase-by-phrase reading time may reflect both initial parsing and subsequent reanalysis. Supporting this argument are the reading times in the Holmes and Mitchell study: The times to read the regions similar in size to the phrase *had been lost* were 1,336 ms when the sentence occurred with *suspected* and 1,493 ms when the sentence occurred with *read*. These times are approximately twice what is obtained when eye movement monitoring techniques are used (Frazier & Rayner, 1982; Rayner & Frazier, 1987).

According to the garden-path model, verb information is not used initially to guide syntactic analysis; instead, verb information is used later to help revise a misparse. The minimal attachment principle determines the initial structure that is adopted by readers, and verb information is then used to revise the initial structure if necessary. Mitchell (1987) obtained results consistent with this general view.[2] In Mitchell's study, subjects read sentences such as #6.

6. a. After the child had sneezed the doctor prescribed a course of injections.
   b. After the child had visited the doctor prescribed a course of injections.

According to the garden-path model, the parser prefers to take the ambiguous phrase *the doctor* as direct object of the first verb rather than as subject of the second. In Sentence 6a, the verb bias goes in the other direction. The verb *sneezed* cannot take a direct object. Therefore, if verb information were used to guide initial syntactic analysis, subjects should be garden-pathed in the 6b version only. Using a self-paced reading task in which subjects read phrase-sized segments and could not look back to previously read segments (noncumulative display), Mitchell found evidence for garden-pathing with *both* verbs. Readers ignored verb information that would have prevented a misparse. Mitchell proposed a model in which two processors are involved in parsing sentences: The first blindly applies syntactic principles such as minimal attachment and late closure, and the second checks this output and revises the syntactic structure if necessary.

The present study had two purposes. The first and primary purpose was to examine whether verb subcategorization information is used by the parser in the initial construction of a syntactic tree. In particular, we explored whether the parser applies the strategy of minimal attachment without regard for verb biases or whether verb information can override minimal attachment. To investigate this question, we required a task sensitive enough to distinguish between initial and subsequent analyses. By monitoring eye fixation location and duration, we could assess garden-path effects on a moment-by-moment basis. It is possible to distinguish (at least to some extent) between initial analysis and reanalyses by comparing first fixation durations with total reading times.

The second purpose of the study was to compare directly the results of a study using eye movement monitoring with

[1] Sentences such as *Susan realized her dream* are acceptable. However, they are rare and occur with a restricted set of objects (e.g., *dream, potential*, and so on).

[2] Mitchell examined the late closure strategy. However, similar predictions hold as with minimal attachment. See Frazier and Fodor (1978).

the results found for word-by-word self-paced reading. Studies comparing the relative worth of similar tasks for exploring reading in general have been conducted (Just, Carpenter, & Woolley, 1982). However, it is important to compare the tasks as a means of exploring parsing in particular (Kennedy & Murray, 1984). In Experiment 1, eye movements were recorded. In Experiments 2 and 3, a word-by-word self-paced reading paradigm was used. These two experiments contrasted the noncumulative display and cumulative display versions of this paradigm. (The former is referred to by Just et al., 1982, as the *moving window technique.*) The experimental and filler sentences were identical across the three experiments.

Experiment 1

To examine the predictions of the minimal attachment and verb guidance hypotheses, four versions of each of 80 sentences were constructed, as illustrated in Table 1. The contrast illustrated by Sentences a and b versus Sentences c and d in Table 1 concerns the bias of the main verb. In a and b, the verb rarely takes a direct object; in c and d, both the direct object and sentence-complement analyses are possible. The two classes of verbs were selected either on the basis of normative data collected by Connine, Ferreira, Jones, Clifton, and Frazier (1985) or according to the intuitions of the experimenters. (The results of the three experiments confirm that the verbs were appropriately biased.) The *a* and *c* versions of each sentence do not contain the complementizer *that*, and the *b* and *d* versions do. When the complementizer is present, subjects should not be garden-pathed, because the sentence is unambiguous.

The sentences were divided into regions, three of which were critical for exploring the hypotheses of this experiment. (Sentences were not presented with region divisions; the regions were used for data analysis only.) The first region (termed the *initial region*) consisted of the subject, main verb, and the complementizer (if present). The second region consisted of only the following noun phrase (the subject of the embedded clause). This region is termed the *ambiguous region* because there is an ambiguity about whether to analyze the noun phrase as the direct object of the verb in the previous region or as the subject of the embedded clause. (Of course, there is no ambiguity in the sentences containing a complementizer, but we use the term *ambiguous region* for expository purposes.) The third region (the *disambiguating region*) contained the embedded verb. This verb disambiguated the sentence toward the subject-of-embedded-clause (the nonminimal attachment) analysis. The fourth region (the *postdisambiguating region*) was composed of the word following the disambiguating verb (or the two words following the verb when the first was a short function word because function words tend not to be fixated). Finally, the fifth region (the *final region*) was the remainder of the sentence. The critical regions for examining the issues in this study are the ambiguous, the disambiguating, and to a lesser extent, the postdisambiguating regions.

Table 1
Example Sentence Frames Used in Experiments 1–3

Region 1	2	3	4	5
a. He wished	Pam	needed	a ride	with him.
b. He wished that	Pam	needed	a ride	with him.
c. He forgot	Pam	needed	a ride	with him.
d. He forgot that	Pam	needed	a ride	with him.

Note. Region 1 = initial region; Region 2 = ambiguous region; Region 3 = disambiguating region; Region 4 = postdisambiguating region. Region 5 = final region. Sentences a and b contain nonminimal attachment verbs while Sentences c and d contain minimal attachment verbs. Sentences a and c do not contain the complementizer while Sentences b and d contain the complementizer.

We monitored subjects' eye movements during the experiment. In numerous studies, the location and duration of fixations have been shown to reveal details of on-line processing of sentences (Carpenter & Daneman, 1981; Ferreira & Clifton, 1986; Frazier & Rayner, 1982; Rayner & Duffy, 1986; Rayner & Frazier, 1987). According to the Frazier and Rayner (1982) garden-path model, subjects would be expected to have little difficulty understanding the Sentences b and d shown in Table 1 because they are unambiguous. For the corresponding versions, Sentences a and c, which do contain a syntactic ambiguity, the garden-path model predicts longer fixation times in the disambiguating region and possibly also in the postdisambiguating region. Even though in Sentence a the verb prohibits a minimal attachment analysis of the direct object, according to the garden-path model, verb information is not available to the parser on its initial structural analysis of a sentence. The parser is therefore predicted to be garden-pathed regardless of verb bias. On the other hand, the verb guidance hypothesis predicts garden-pathing effects with Sentence c but not with Sentence a because in the latter the bias of the verb is inconsistent with a minimal attachment analysis.

Method

Subject. Twelve members of the University of Massachusetts community were paid $5 per hour to participate in the experiment. All participants had normal uncorrected vision and were not aware of the purpose of the experiment.

Apparatus. Eye movements were recorded by a Stanford Research Institute Dual Purkinje Eyetracker with a resolution of 10 min of arc. The eyetracker was interfaced with a Hewlett-Packard 2100 computer that controlled the experiment. Eye movements were recorded from the right eye, and viewing was binocular.

Sentences were presented on a Hewlett-Packard 1300A computer screen (CRT). The luminance on the CRT was adjusted at the beginning of the experiment for each subject and maintained at a comfortable level of brightness throughout the session. The subject's eye was 46 cm from the CRT so that three characters equaled 1° of visual angle. The room was dark except for a dim light source which allowed the experimenter to score the subject's responses to comprehension questions that were asked throughout the experiment.

Materials. The materials were divided into four lists, and 3 subjects viewed each list. A single list consisted of 80 experimental sentences and 72 fillers.

For each experimental sentence, a sentence frame such as #7 was created.

7. Pam ______ed (that) Chris bakes tasty cakes.

Each frame was associated with two verbs; the verbs for Sentence 7 were *bragged* and *guessed*. The word *bragged* does not permit a direct object; we will refer to this class of verbs as the *nonminimal attachment* verbs. This term is meant to convey that these verbs are strongly biased for a nonminimal interpretation of the ambiguous noun phrase. In contrast, the verb *guessed* permits either a direct object or sentence complement; this class will be referred to as the *minimal attachment* verbs. This term is used because these verbs are more strongly biased for a minimal attachment analysis of the ambiguous noun phrase than is the other set of verbs.

For each frame, the minimal and nonminimal attachment verbs had to be semantically sensible within the sentence, and across verb bias, the verbs were matched on length and frequency. The frame could occur with or without the complementizer *that*. Thus, for each frame there were four different versions.

The same pair of verbs was assigned to four different frames. For the *bragged-guessed* pair, the four frames were Sentence 7 above and Sentences 8–10.

8. Sam ______ed (that) Sally saved fifty dollars.
9. He ______ed (that) chess amuses the new kid.
10. She ______ed (that) Iowa charges a low tax.

For any one frame, only one version occurred per list. Versions were assigned to lists by a Latin-square procedure. Because each verb pair was assigned to four different frames, each verb appeared twice in a list, once with a complementizer and once without. This procedure was employed to maximize the number of items that could be created from the small set of verbs possessing the relevant properties.

The 80 experimental sentences were embedded in 72 filler sentences, which were of a wide variety of sentence types. The experimental sentences are given in the Appendix, and the filler sentences can be found in Henderson and Ferreira (1990).

Procedure. When a subject arrived for the experiment, a bite bar was prepared to eliminate head movements during the experiment. The eye tracking system was then calibrated for each subject, a procedure that took approximately 10 min. At the beginning of the session, each subject read 10 practice sentences. After the practice sentences, the subjects read 80 experimental sentences and 72 filler sentences. The order of sentence presentation was randomized for each subject[3].

A trial consisted of the following events: First, the experimenter checked the calibration of the eye movement system, and the system was recalibrated when necessary. Second, the subject was asked to fixate a cross on the left side of the CRT when he or she was ready for a sentence. Approximately 500 ms after the cross was fixated, a single sentence was presented on the CRT. The sentences always fit on one horizontal line across the CRT. The instructions in this experiment, as in Experiments 2 and 3, were for the subjects to read each sentence and to press a button when they understood it. Subjects were informed that they would be asked a comprehension question occasionally. The button press caused the sentence to disappear and the calibration crosses to reappear. On 20% of the trials, subjects were asked a simple *yes/no* comprehension (for both experimental and filler sentences) to ensure that they were reading the sentences for comprehension. Because subjects were virtually flawless in answering these questions, the questions were not scored. The experiment lasted about 1 hr.

Results

The following analyses exclude trials on which (a) the eyetracker lost track of the eye position, (b) the region was not fixated, or (c) fixation durations were less than 100 ms or greater than 2,000 ms (fewer than 5% of all trials in total). In order to determine the effects of the manipulated variables, several aspects of the eye movement record were analyzed. For each of the three critical regions, we will report mean first fixation duration (the time spent in a region during the initial fixation in that region, excluding refixations within the region), mean total reading time (the total amount of time spent within a region, including refixations prior to leaving the region and rereads resulting from eye movements back to the region), and the number of regressions to a region (eye movements from a subsequent region back to a previous region)[4]. The analyses were conducted by treating both subjects and items as random effects (F_1 and F_2, respectively).

First fixation duration. The mean first fixation durations on each of the three critical regions in the four experimental conditions are shown in Table 2. In the ambiguous region, there was no effect of either verb bias ($Fs < 1$) or complementizer presence, $F_2(1, 11) = 1.68$, $MS_e = 6{,}414$, $p > .20$, $F_2(1, 79) = 1.38$, $MS_e = 7{,}812$, $p > .20$, nor was there an interaction between these two variables ($Fs < 1$). The absence of an effect of either variable in this region suggests that any increases in processing time due to the presence of the complementizer were completed prior to the ambiguous region.

In the disambiguating region, mean first fixation duration in the nonminimal attachment verb condition was 216 ms, and in the minimal attachment verb condition, 208 ms. This difference did not approach significance ($Fs < 1$). Contrary to the lexical hypothesis, reading times were no shorter with nonminimal attachment verbs than with minimal attachment verbs. Consistent with the garden-path model, first fixation duration was longer when the complementizer was absent (223 ms) than when it was present (201 ms), $F_1(1, 11) = 8.41$, $MS_e = 3{,}912$, $p < .05$, $F_2(1, 79) = 9.00$, $MS_e = 7{,}251$, $p < .005$. This result suggests that without a complementizer, subjects assumed a direct object analysis and diagnosed their error in the disambiguating region. The absence of an interaction between these two variables, $F_1(1, 11) = 1.01$, $F_2 < 1$,

[3] In this experiment we also sought to investigate the viability of a second measure of processing difficulty: effect of foveal processing difficulty on the perceptual span. If the foveal word were difficult to process, the size of the perceptual span for parafoveal information might be reduced (Henderson, 1988; Rayner, 1986). We examined this issue by manipulating the availability of parafoveal information in the postdisambiguating region prior to an eye movement into that region. The results from that manipulation were entirely consistent with the results reported here: The perceptual span was reduced when the complementizer was absent compared with when it was present. This effect did not interact with verb type. See Henderson and Ferreira (1990) for a more complete description.

[4] Mean gaze durations (total time spent in a region prior to an eye movement out of the region, i.e., excluding rereads resulting from regressions) were also analyzed. The pattern of data was similar to that found with first fixation duration but was not statistically reliable. In addition, there was some tendency for the effect of the disambiguating word to appear during fixation on the prior (ambiguous) word in the gaze duration data, presumably because attention was sometimes directed toward the disambiguating word during additional fixations on the ambiguous word.

indicates that verb bias did not influence the extent of the garden path. Subjects were as likely to attempt a minimal attachment analysis of the sentences when they contained nonminimal attachment verbs as when they contained minimal attachment verbs.

Finally, in the postdisambiguating region, reading times were equivalent regardless of verb type (Fs < 1). There was no significant effect of complementizer presence, $F_1(1, 11) = 2.65$, $MS_e = 10{,}375$, $p > .10$, $F_2(1, 79) = 1.09$, $MS_e = 8{,}416$, $p > .25$, nor was there an interaction, $F_1(1, 11) = 1.87$, $MS_e = 7{,}253$, $p > .15$, $F_2(1, 79) = 2.80$, $MS_e = 12{,}235$, $p > .10$. The results for this region suggest that reading times are quickly restored to their predisambiguation state.

The pattern that emerges from the first fixation data is that reading times were constant until the disambiguating region was encountered. At that point, reading times increased when the complementizer was absent, regardless of verb biases. By the next region, reading times converged across conditions.

Total reading time. The mean total reading times in each of the three critical regions for the four conditions are shown in Table 3. In the ambiguous region, there was no effect of verb bias (255 vs. 245 ms for nonminimal attachment verbs and minimal attachment verbs, respectively), $F_1 < 1$ and $F_2(1, 79) = 2.05$, $MS_e = 8{,}602$, $p > .15$. Unlike first fixation duration, total reading times were shorter in this region when the complementizer was present (235 ms) than when it was absent (264 ms). The effect was marginal by subjects and significant by items, $F_1(1, 11) = 4.00$, $MS_e = 14{,}864$, $p < .07$, $F_2(1, 79) = 19.03$, $MS_e = 8{,}094$, $p < .005$. The interaction was not significant (both Fs < 1). These results suggest that subjects returned to the ambiguous region after they had been garden-pathed in the disambiguating region when the complementizer was absent.

Table 2
Mean First Fixation Duration (in Milliseconds) in the Ambiguous, Disambiguating, and Postdisambiguating Regions by Verb Type and Complementizer Presence: Experiment 1

	Complementizer presence		
Verb type	Absent	Present	*M*
	Ambiguous region		
NMA verb	214	208	211
MA verb	217	200	209
M	216	204	
	Disambiguating region		
NMA verb	230	200	216
MA verb	215	201	208
M	223	201	
	Postdisambiguating region		
NMA verb	321	288	305
MA verb	308	302	305
M	314	295	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Table 3
Mean Total Reading Time (in Milliseconds) in the Ambiguous, Disambiguating, and Postdisambiguating Regions by Verb Type and Complementizer Presence: Experiment 1

	Complementizer presence		
Verb type	Absent	Present	*M*
	Ambiguous region		
NMA verb	268	241	255
MA verb	260	230	245
M	264	235	
	Disambiguating region		
NMA verb	269	225	247
MA verb	284	234	259
M	276	230	
	Postdisambiguating region		
NMA verb	420	401	410
MA verb	421	439	430
M	420	420	

Note. NMA = nonminimal attachment; MA = minimal attachment.

In the disambiguating region, verb bias did not produce a significant effect (247 vs. 259 ms for the nonminimal attachment and minimal attachment verbs), $F_2(1, 11) = 1.87$, $MS_e = 5{,}520$, $p > .15$, $F_2(1, 79) = 1.10$, $MS_e = 8{,}405$, $p > .25$. When the complementizer was absent, subjects spent 46 ms longer in the region compared with when it was present (276 ms vs. 230 ms), $F_1(1, 11) = 11.22$, $p < .01$, $MS_e = 13{,}990$, $F_2(1, 79) = 17.52$, $MS_e = 15{,}732$, $p < .001$. These two variables did not interact (both Fs < 1). These data mirror those found when first fixation duration is used and indicate that readers spent more time in the disambiguating region if they had been garden-pathed.

Finally, in the postdisambiguating region, there was some tendency for verb bias to affect total reading time. The total reading time in this region was 410 ms for the nonminimal attachment verbs and 430 for the minimal attachment verbs. The effect was significant by subjects, $F_1(1, 11) = 4.76$, $MS_e = 5{,}781$, $p < .05$, but not by items, $F_2 < 1$, perhaps suggesting that this effect is peculiar to a small subset of items. Complementizer presence had no effect in this region (both Fs < 1), and there was no interaction between the two variables, $F_1(1, 11) = 1.74$, $MS_e = 14{,}527$, $p > .20$, $F_2(1, 79) = 2.24$, MS_e 30,464, $p > .10$.

Total reading times in the more peripheral regions surrounding the critical regions were also analyzed. Reading times by condition on the first word, the main verb, and the complementizer (when present), are shown in Table 4. There were no effects of the experimental variables on these regions. For the first word, all Fs were less than 1. For the main verb, all Fs approximated 1 except for the effect of verb bias over subjects, $F_1(1, 11) = 3.32$, $MS_e = 737$, $p = .09$. Finally, total reading time did not differ on the complementizer as a function of verb bias (Fs < 1).

Table 4
Mean Total Reading Time (in Milliseconds) for the First Word, Main Verb, and Complementizer (if Present) by Verb Type and Complementizer Presence: Experiment 1

Verb type	Complementizer presence: Absent	Present	*M*
	First word		
NMA verb	236	231	234
MA verb	222	207	214
M	229	219	
	Main verb		
NMA verb	323	317	320
MA verb	314	297	306
M	318	307	
	Complementizer		
NMA verb		217	
MA verb		224	
M		220	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Table 5 shows total reading times on the final region of the sentence (the last one or two words). For the final region, there was a tendency toward a complementizer presence effect, $F_1 < 1$, $F_2(1, 79) = 6.03$, $MS_e = 29{,}343$, $p < .05$. Neither the effect of verb bias nor the interaction of the two factors approached significance ($Fs < 1$).

Table 6 shows the mean total reading times for the entire sentence by condition. Collapsed over conditions, the mean total reading time for the sentences was 1,535 ms. There were no effects of either verb bias or complementizer presence and no interaction (all $ps > .25$).

The pattern that emerges from the total reading time per region data is that readers focused their efforts on the ambiguous and disambiguating regions when they were trying to construct the correct parse of the sentence. They required increased time in these regions if the complementizer was not present in the sentence. Verb bias appears to have had some effect in the postdisambiguating region, although it is difficult to argue that the effect was due to reanalysis toward a nonminimal attachment analysis because verb bias did not interact with complementizer presence.

Regressions. Because of the infrequency of regressive eye movements across regions, statistical treatment of these data was not possible. We report the data because the pattern was predicted and is easily interpreted.

The regression data are shown in Table 7. We report the total number of regressions to the ambiguous region from the disambiguating region alone, and from any point in the sentence beyond the ambiguous region; we also report regressions to the disambiguating region from all subsequent regions. As the table indicates, regressions were more frequent when the complementizer was absent than when it was present, replicating the findings of Rayner and Frazier (1987). Verb bias appeared to have little effect on regressions to the ambiguous region but a noticeable effect on regressions to the disambiguating region. In the latter case, reanalysis appeared to be easier with the nonminimal attachment verbs (4 regressions) than with the minimal attachment verbs (21 regressions).

Discussion

The results of this experiment using eye movement recording support Frazier and Rayner's (1982) garden-path model of parsing and offer little support for the verb guidance hypothesis. Readers were as likely to initially misanalyze sentences when they contained nonminimal attachment verbs as minimal attachment verbs. The first fixation duration measure, which is more revealing of early stages of syntactic processing than is total reading time (Frazier & Rayner, 1982), indicated that readers initially assumed a minimal attachment analysis of the sequence *X "verbed" Y* even when the verb was inconsistent with this syntactic analysis. Only upon reaching the disambiguating word (the embedded verb) did they detect their error and begin the work of reanalyzing the sentence. As predicted by the garden-path model, subjects who read the sequence *X "verbed" that Y* analyzed the sentences correctly because the complementizer eliminated the ambiguity of *Y*.

The total reading time and regression data provide further support for this argument. Subjects spent more time in the ambiguous region when the complementizer was absent than when it was present, indicating that they were reanalyzing the region and trying to come up with the correct analysis of the sentence. This effect persisted through the disambiguating region. Subjects made regressive eye movements back to the disambiguating region more often when the complementizer was absent and the verb was biased toward a minimal attachment reading than in the other three conditions, a finding suggesting that subjects could reanalyze the sentences toward a nonminimal analysis more efficiently with a nonminimal attachment verb than with a minimal attachment verb.

In summary, then, consistent with the garden-path model, verb bias had no effect on initial parsing of the sentences, though verb bias may have been used at a later stage to aid in the reanalysis of a misparsed sentence. Although our evidence for the latter claim is not overwhelming, other studies have demonstrated the use of verb information in sentence reanalysis (Mitchell, 1987), as does Experiment 2 below.

Table 5
Mean Total Reading Time (in Milliseconds) on the Remainder of the Sentence Following the Postdisambiguating Region by Verb Type and Complementizer Presence: Experiment 1

Verb type	Complementizer presence: Absent	Present	*M*
NMA	369	367	368
MA	363	341	352
M	366	354	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Experiment 2

Experiment 1 provided support for the Frazier and Rayner (1982) garden-path model of parsing and was inconsistent with the verb guidance hypothesis. These results are at odds with a few studies demonstrating effects of verb bias but using a different task, namely, the self-paced reading task. The present experiment was conducted in order to determine whether qualitatively different results would be obtained from eye movement monitoring and self-paced reading. Specifically, we examined whether the latter task would produce a pattern of results more consistent with the verb guidance hypothesis, as has been demonstrated by Holmes and her colleagues (Holmes, 1987; Mitchell & Holmes, 1985). A second purpose of the experiment was to verify that the verbs were, in fact, biased appropriately.

Method

Subjects. Subjects were 24 University of Alberta undergraduates who participated in the experiment in exchange for partial credit in their introductory psychology courses. Subjects were not aware of the purpose of the experiment.

Materials. The same experimental items used in the first experiment were used here as well. The 80 experimental sentences were intermixed with the same 72 filler sentences from the previous experiment.

Procedure. Subjects were seated in front of a computer monitor. At the beginning of each trial, a sentence appeared on the screen but with an underline in place of every letter (word spaces remained). Subjects were told to push a button to reveal the first word of the sentence. At that point, the underlines were replaced by the appropriate letters. Subjects read the word and, once they understood it, pushed the button for the next word. Upon pushing the button, the previous word was replaced with underlines. Subjects proceeded in this fashion until the entire sentence was read. On a random 10% of the trials, the experimental sentences were followed by a *true/false* question. Subjects answered these questions by pushing a *true* or *false* button (neither of which was the pacing button used for the reading task). Most subjects answered all questions correctly, and no subject made more than one error.

Results

Reading times in the three critical regions are shown in Table 8. In the ambiguous region, reading times were equivalent regardless of verb bias (Fs < 1) and complementizer presence, $F_1(1, 23) = 1.43$, $MS_e = 4{,}799$, $p > .20$, $F_2(1, 79) = 2.19$, $MS_e = 12{,}380$, $p > .10$. There was no interaction between the two factors (Fs < 1).

In the disambiguating region there was no effect of verb bias (Fs < 1). However, consistent with the garden-path model and the results of Experiment 1, there was a robust effect of complementizer presence, $F_1(1, 23) = 14.8$, $MS_e = 5{,}533$, $p < .005$, $F_2(1, 79) = 15.3$, $MS_e = 18{,}191$, $p < .001$. Mean reading times were 449 ms in the complementizer-present condition and 508 ms in the complementizer-absent condition. There was no indication of a Complementizer Presence × Verb Bias interaction (Fs < 1).

Finally, in the postdisambiguating region,[5] there was no effect of verb bias alone (Fs < 1). However, unlike the data from the eye movement study, there was a continued effect of complementizer presence into this region, $F_1(1, 23) = 10.4$, $MS_e = 1{,}555$, $p < .005$, $F_2(1, 79) = 6.64$, $MS_e = 8{,}683$, $p < .05$, and importantly, there was a significant interaction of verb bias and complementizer presence, $F_1(1, 23) = 4.98$, $MS_e = 1{,}532$, $p < .05$, $F_2(1, 79) = 5.17$, $MS_e = 5{,}485$, $p < .05$. As can be seen in Table 8, reading times were most elevated when the complementizer was absent and the verb allowed a minimal attachment reading. When the comple-

Table 6
Mean Total Sentence Reading Time (in Milliseconds) by Verb Type and Complementizer Presence: Experiment 1

Verb type	Complementizer presence: Absent	Present	*M*
NMA	1,518	1,534	1,526
MA	1,515	1,573	1,544
M	1,517	1,553	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Table 7
Total Number of Regressions to the Ambiguous Region From the Disambiguating Region and From all Subsequent Regions, and to the Disambiguating Region From all Subsequent Regions by Verb Type and Complementizer Presence: Experiment 1

Verb type	Complementizer: Absent	Present	Total
From disambiguating region to ambiguous region			
NMA	10	4	14
MA	11	5	16
Total	21	9	
From all subsequent regions to ambiguous region			
NMA	16	11	27
MA	17	9	26
Total	33	20	
From all subsequent regions to disambiguating region			
NMA	4	7	11
MA	21	8	29
Total	25	15	

Note. NMA = nonminimal attachment; MA = minimal attachment.

[5] In Experiment 2, the postdisambiguating region consisted of the first word following the disambiguating word. In Experiment 1, if the postdisambiguating region began with a function word, then the region included both the function word and following content word. This procedure was followed because subjects tend to skip short function words. Because in Experiment 2 subjects had to execute a button-press to every word, a reading time measure could be derived from the first word following the disambiguating word regardless of its syntactic class or length.

mentizer was absent but the verb did not permit a minimal attachment reading (i.e., was biased toward nonminimal attachment), subjects had less difficulty.

Word-by-word reading times for the more peripheral regions were also analyzed. Table 9 shows the reading times on the first word, main verb, and on the complementizer when it occurred in the sentence, as a function of condition. As in the eye movement experiment, there were no significant effects in this region. For the first word, all *F*s approximated 1. For the main verb, there was a nonsignificant tendency toward a Verb Bias × Complementizer Presence interaction, $F_1(1, 23) = 3.63$, $MS_e = 2{,}458$, $p < .10$, $F_2(1, 79) = 3.83$, $MS_e = 7{,}949$, $p < .10$. This potential interaction was caused by elevated reading times in the nonminimal-verb complementizer-present condition, and it appears to be spurious because the two nonminimal sentences were identical up to that point. Reading time on the complementizer did not differ as a function of the verb bias, $F_1(1, 23) = 1.18$, $MS_e = 1{,}341$, $p > .15$, $F_2(1, 79) = 1.49$, $MS_e = 6{,}122$, $p > .20$.

Reading times in the final region of the sentence (the last two or three words) are shown in Table 10. For this region, there were no effects of either variable (all *F*s < 1), except for a marginal interaction by items, $F_2(1, 79) = 3.46$, $MS_e = 21{,}802$, $p < .10$.

Mean total reading time for the sentences collapsed over conditions was 3,388 ms, about twice as long as the total reading time for the same sentences in Experiment 1. Also unlike Experiment 1, in the present experiment total reading time was affected by condition, as shown in Table 11. There was a marginal effect of verb bias, $F_1(1, 23) = 3.41$, $MS_e = 113{,}753$, $p < .10$, $F_2(1, 79) = 2.78$, $MS_e = 219{,}434$, $p < .10$, a significant effect of complementizer presence, $F_1(1, 23) = 15.0$, $MS_e = 127{,}632$, $p < .005$, $F_2(1, 79) = 37.2$, $MS_e = 180{,}612$, $p < .001$, and a significant interaction between the two factors, $F_1(1, 23) = 3.99$, $MS_e = 110{,}174$, $p = .05$, $F_2(1, 79) = 6.77$, $MS_e = 173{,}921$, $p < .05$. As can be seen in Table 11, the interaction supports the notion that verb bias can affect reanalysis processes following a garden-path effect: Reading times were faster in the complementizer-absent condition when the verb was biased toward a nonminimal attachment reading.

Table 8
Mean Reading Time per Region (in Milliseconds) in the Ambiguous, Disambiguating, and Postdisambiguating Regions by Verb Type and Complementizer Presence: Experiment 2

Verb type	Complementizer presence: Absent	Present	*M*
	Ambiguous region		
NMA	480	464	472
MA	473	455	464
M	476	460	
	Disambiguating region		
NMA	500	448	474
MA	515	450	483
M	508	449	
	Postdisambiguating region		
NMA	463	455	459
MA	485	441	463
M	474	448	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Table 9
Mean Reading Time per Region (in Milliseconds) for the First Word, Main Verb, and Complementizer (if Present) by Verb Type and Complementizer Presence: Experiment 2

Verb type	Complementizer Presence: Absent	Present	*M*
	First word		
NMA verb	396	411	403
MA verb	409	400	405
M	402	406	
	Main verb		
NMA verb	451	485	468
MA verb	458	454	456
M	454	469	
	Complementizer		
NMA verb		451	
MA verb		437	
M		444	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Discussion

The results of this experiment using the noncumulative word-by-word self-paced reading task replicated the main finding of Experiment 1 relevant to the garden-path model: Reading times in the disambiguating region increased when the complementizer was absent, regardless of the bias of the main verb of the sentence. The conclusion, therefore, is that verb bias cannot block the garden-path effect.

Although the garden-path model predicted that the bias of the verb would not affect the initial analysis of the parser, it would be reasonable to suppose that verb bias should affect the ultimate analysis of the sentence arrived at by the parser by exerting an influence on reanalysis processes. In Experiment 1, there was some indication that verb bias did affect reanalysis because both the number of regressions and the total reading times on the postdisambiguating region were less when the verb was biased toward a nonminimal attachment reading. However, neither of those effects was overwhelming, leaving open the possibility that the verbs chosen were not sufficiently biased to produce an effect on the initial parse of the sentence. The results of Experiment 2 provide evidence against this possibility. In Experiment 2, the same sentences were used as in Experiment 1, and the results indicated that verb bias was used by the parser during reanalysis, as indicated by reading times in the postdisambiguating region and total reading times.

Experiment 3

Some researchers in psycholinguistics have used the same task we used in Experiment 2, but with a cumulative display (e.g., Holmes, 1987; Holmes, Kennedy, & Murray, 1987). The appeal of this task is that it allows the reader to reread segments and so may be sensitive to reanalysis processes. On the other hand, Just et al. (1982) reported that this technique did not reflect on-line sentence processing because most subjects adopted a fairly reasonable strategy of rapidly pushing the self-pace button to reveal segments until the entire sentence was visible and then reading the sentence. Using the same materials and general procedures as in Experiment 2, we conducted Experiment 3 to determine whether the cumulative word-by-word paradigm would be sensitive to on-line parsing processes.

Method

Twenty-four University of Alberta undergraduates participated in this experiment. None had participated in the previous studies.

The same method and procedure were followed here as in Experiment 2, except that the words of the sentence remained visible as the subject read the sentence.

Results

Consistent with Just et al.'s (1982) study of cumulative self-paced reading, few significant effects were obtained in this experiment. The results in the critical regions and for total reading time are shown in Table 12. The only significant effects were the following: In the disambiguating region, there was a marginal effect of complementizer presence, $F_1(1, 23) = 5.20$, $MS_e = 2{,}095$, $p < .05$, $F_2(1, 79) = 3.12$, $MS_e = 9{,}139$, $p < .10$. In total reading time for the sentences, the effect of verb was significant: Sentences with nonminimal attachment verbs were read faster than those with minimal attachment verbs, 3,318 versus 3,492 ms, $F_1(1, 23) = 5.94$, $MS_e = 121{,}934$, $p < .05$, $F_2(1, 79) = 6.13$, $MS_e = 451{,}584$, $p < .05$.

Table 10
Mean Total Reading Time (in Milliseconds) on the Remainder of the Sentence Following the Postdisambiguating Region by Verb Type and Complementizer Presence: Experiment 2

Verb type	Complementizer presence: Absent	Present	*M*
	Verb type		
NMA	806	836	821
MA	868	821	844
M	837	829	
	Final word		
NMA	620	598	609
MA	688	594	641
M	654	596	

Note. NMA = nonminimal attachment; MA = minimal attachment.

Table 11
Mean Total Sentence Reading Time (in Milliseconds) by Verb Type and Complementizer Presence: Experiment 2

Verb type	Complementizer presence: Absent	Present	*M*
NMA	3,116	3,533	3,325
MA	3,378	3,525	3,452
M	3,247	3,529	

Note. NMA = nonminimal attachment; MA = minimal attachment.

These two effects are consistent with the pattern obtained in the first two experiments. The garden-path effect occurred in the disambiguating region when readers first realized that their initial syntactic analysis could not be correct. This initial effect occurred regardless of verb bias. Verb bias did seem to help subjects find the correct analysis of the sentence, however, as indicated by total sentence reading time.

The effects were not as robust here as in Experiment 2. Notice that reading times across the regions were much faster in this experiment than in the previous one, and yet the total sentence reading times were comparable. This pattern of reading times tends to confirm the Just et al. (1982) argument that button-pressing and comprehension are largely decoupled in the cumulative self-paced paradigm because subjects wait to process the sentence until it is entirely revealed.

General Discussion

In this study we were interested in the effect of verb bias on the initial syntactic parse of a sentence during reading. In order to explore this issue, experimental sentences that varied in terms of verb bias and syntactic ambiguity were presented to subjects in three reading paradigms.

In Experiment 1 we used eye movement monitoring and found that initial parsing strategies were unaffected by verb bias. Subjects initially adopted a minimal attachment analysis of a sentence when it was syntactically ambiguous (i.e., did not contain a complementizer), even when the main verb did not permit such an analysis. Subjects resorted to the nonminimal attachment structure only upon encountering the disambiguating region of the sentence. Verb bias did not prevent the misanalysis, but judging from the regression data, it seemed to facilitate reanalysis.

In Experiment 2, in which we used a noncumulative word-by-word self-paced reading paradigm, a garden-path effect consistent with the minimal attachment principle was again found, and this initial parsing strategy was unaffected by verb bias. In this experiment, a more robust effect of verb bias was found later in the sentence, suggesting that verb bias can aid in the reanalysis process. In Experiment 3, a similar pattern

Table 12
Mean Reading Time per Region in the Ambiguous, Disambiguating, and Postdisambiguating Regions, and Mean Total Sentence Reading Time (in Milliseconds) by Verb Type and Complementizer Presence: Experiment 3

	Complementizer presence		
Verb type	Absent	Present	*M*
	Ambiguous region		
NMA	303	302	302
MA	315	312	313
M	309	307	
	Disambiguating region		
NMA	348	320	334
MA	334	320	327
M	341	320	
	Postdisambiguating region		
NMA	367	357	362
MA	381	366	374
M	374	361	
	Total sentence reading time		
NMA	3,214	3,422	3,318
MA	3,455	3,529	3,492
M	3,335	3,475	

was obtained, except that the effects (particularly the verb effect) were substantially weaker than in Experiment 2.

Our finding that subject–verb–clause sentences are harder to parse when the complementizer is absent is consistent with results from a number of studies (Frazier & Rayner, 1982; Rayner & Frazier, 1987). However, some researchers have claimed to have evidence to the contrary (Holmes et al. 1987; Kennedy, Murray, Jennings, & Reid, 1990). Holmes et al. (1987) proposed that the difficulty associated with sentences such as *Mary knew Bill was lying* compared with *Mary knew Bill well* is due not to the attachment ambiguity associated with the postverbal noun phrase, but rather to the extra processing needed to construct a two-clause sentence compared with a one-clause sentence. Using cumulative self-paced reading, they found no difference in reading time for sentences consisting of the sequence subject–verb–clause when the sentences contained an overt complementizer compared with those where the complementizer was absent. In contrast, using eye movement monitoring, Rayner and Frazier (1987) found that the null complementizer cases were, in fact, more difficult, and they argued that the difficulty associated with those cases could not be detected with the cumulative self-paced reading task used by Holmes et al. (1987). Our evidence supports Rayner and Frazier's argument: In Experiment 3, we obtained weak effects of the complementizer on reading times with the cumulative task. In contrast, Experiments 1 and 2 demonstrated robust effects of complementizer presence.

Further, our results are not due to artifacts relating to the way sentences were displayed across the screen to subjects. Kennedy et al. (1990) suggested that the line breaks in the Rayner and Frazier experiment were located so as to induce garden-path effects. The fact that we obtained effects similar to those of Rayner and Frazier even though our sentences were only one line long renders this argument implausible.

In summary, our results demonstrate that sentences lacking an optional complementizer are more difficult to process than those containing the complementizer. These results indicate that the parser operates in a manner consistent with the garden-path model. This tendency for the parser to be garden-pathed is not due to the placement of line breaks. In addition, the absence of a verb effect indicates that the phenomenon of garden-pathing is not restricted to a small set of verbs, but rather appears to occur regardless of verb bias.

Methodological Issues

The results of this study are potentially useful in sorting out some extant methodological issues that have arisen in discussions of parsing strategies in general and the garden-path model in particular. Evidence consistent with the garden-path model has generally been found with eye movement monitoring (e.g., Ferreira & Clifton, 1986; Frazier & Rayner, 1982; Rayner & Frazier, 1987; Rayner et al., 1983). On the other hand, when other reading paradigms have been used, the findings have been more varied. For example, both the current study and that of Ferreira and Clifton (1986) found evidence for the minimal attachment principal by using a noncumulative word-by-word self-paced reading paradigm. On the other hand, researchers using a variety of button-pressing paradigms (e.g., Altmann & Steedman, 1988; Holmes, 1987; Mitchell & Holmes, 1985) have tended to find evidence against the garden-path model.

There are several reasons to believe that eye movement monitoring and noncumulative word-by-word reading, in that order, are the two most preferable methodologies for exploring initial parsing processes. In the case of eye movement monitoring, the reader arrives at the experimental session already knowing how to make eye movements in the service of comprehension. Because the subject does not need to learn any new skills, the reading situation reflects the same processes that would take place in any reading situation, and there is less likelihood that task-specific strategies can influence the data.

Second, it has been argued that the oculomotor system is functionally coupled to the attentional system in such a way that the point of fixation of the eyes is systematically related to the point of attentional focus (Henderson & Ferreira, 1990; Henderson, Pollatsek, & Rayner, 1989; Inhoff, Posner, Pollatsek, & Rayner, 1989; McConkie, 1979; Morrison, 1984; Rayner, Murphy, Henderson, & Pollatsek, 1989). Because of this coupling, eye movement position and duration will closely reflect ongoing cognitive and linguistic processing (see e.g., Just & Carpenter, 1980, 1987; Rayner, 1978; Rayner & Pollatsek, 1989). There is less reason to believe that the current point of attentional focus during on-line sentence processing will be closely coupled with button pressing. In the case of the noncumulative word-by-word version of the paradigm, it seems likely that subjects are focusing attention on the single word that is currently on the screen. But even in this best case, it is still doubtful that the motor command to press the button is as integrated into the reading process as is the motor command to move the eyes in natural reading.

Other button-pressing tasks beyond the noncumulative word-by-word task introduce several problems. For instance, in the case of the cumulative version of the word-by-word paradigm, there is no guarantee that subjects will focus attention on the last word to be revealed. Instead, readers often seem first to reveal a number of words or even the whole sentence and then to read the sentence once it is entirely available. Further, the more attention becomes decoupled from the word that is being responded to by the button press, the more likely it becomes that both initial and reanalysis processes will be reflected in the same measure. Because the garden-path model makes specific predictions about initial parsing decisions, it is crucial that a measure be used that is sensitive to that stage alone. Finally, we suspect that as the reading task becomes less like natural reading, there will be a much greater chance that subject strategies will influence the results of an experiment. For example, Holmes (1987) has used a paradigm in which subjects made a grammaticality decision on each word as it was read. The implications of such studies for the garden-path model are difficult to evaluate because the sources of information used by the subject may be different in both timing and kind from the sources used during natural reading.

An interesting question is why the use of verb information was more exaggerated in the word-by-word noncumulative paradigm compared with the eye movement paradigm. We speculate that verb information is more useful in a situation where reanalysis is more difficult. Given that the parser has encountered difficulty in the complementizer-absent condition upon reaching the disambiguating word, the options available are different in the two paradigms. In the eye movement study, subjects could look back to the region of difficulty and reread it in an attempt to find the correct parse. In the word-by-word study, this option was not open, and subjects instead had to slow down on the next word (the postdisambiguating word) as reanalysis proceeded. If reanalysis is more difficult in the word-by-word paradigm than in the eye movement paradigm because the reader cannot look back to previously read material in the former case, then it seems plausible that readers might have relied more heavily on the verb information to aid their reanalysis in the word-by-word experiment (Ferreira & Henderson, in press).

Verb Bias and the Garden-Path Model of Parsing

The main conclusion of these experiments is clear: Verb biases do not initially influence the way the parser constructs a syntactic tree. The syntactic parser adopts the minimal attachment analysis without regard for the lexical biases of the verbs in the sentences being read. These results are consistent with the model of sentence comprehension proposed by Frazier (1978, 1987). Parsing strategies such as minimal attachment are followed blindly and cannot be overridden by nonphrase structural sources of information such as lexical information. In addition, Frazier and Rayner (1982) obtained weak garden-path effects with sentences containing short ambiguous regions. We found that even with our short ambiguous regions, the garden-path effects were quite robust.

A potential criticism of these conclusions is that we did not actually test the minimal attachment principle. The minimal attachment principle states that for any sequence NP–V–NP (noun phrase–verb–noun phrase), the second NP will be interpreted as a direct object. It could be argued that in order to test the minimal attachment principle, it is necessary to contrast sentences having a main verb followed by a direct object with sentences where the main verb is followed by a sentential complement. The sentences used in the present study were all of the form subject–verb–clause, and we compared easy and difficult versions by either including or excluding the complementizer associated with the embedded clause. It could be argued that our results demonstrate only that the parser has an easier time parsing subject–verb–clause constructions with the complementizer and do not provide specific support for minimal attachment.

However, it is important to provide an account of the preference for complementizers in subject–verb–clause constructions. The minimal attachment principle provides such an account, for it states that a noun phrase following a main verb will be minimally attached as a direct object, and the noun phrase will subsequently have to be reanalyzed if it is followed by a verb. The minimal attachment principle not only provides an account of the preference, but it also predicts precisely where the difficulty caused by the missing complementizer will occur. On the view that sentences without complementizers are simply more difficult overall than sentences with complementizers, one might expect the difficulty to occur on the noun phrase following the main verb because the parser cannot unambiguously analyze this phrase. However, as predicted by the garden-path model, we found that the difficulty occurs on the embedded verb (see also Rayner & Frazier, 1987). The difficulty occurs on the embedded verb because the verb signals that a direct object analysis of the ambiguous noun phrase is incorrect.

Our experiments were designed not only to test the minimal attachment principle but also to explore its interaction with verb subcategorization information. As stated above, the experiments show that the principle is not overridden in the presence of such information. Minimal attachment operates during the parser's first pass through a sentence. Only in later passes does the parser consult information about verb biases.

The lack of initial use of verb information by the parser is inconsistent with the general class of interactive models of parsing, which presume that all sources of information, whether lexical, syntactic, semantic, or discourse–contextual, communicate in an unconstrained fashion to produce the most plausible reading of a sentence at the earliest stages of sentence comprehension (Marslen-Wilson, 1975; McClelland, 1987; Taraban & McClelland, 1988). Our results add to the growing literature (Clifton & Ferreira, 1987, 1990; Ferreira & Clifton, 1986; Frazier & Rayner, 1982; Mitchell, 1987; Rayner et al., 1983; Rayner & Frazier, 1987) suggesting that the parser does not operate in this unconstrained fashion. Initially, the parser uses only phrase–structural information to construct a syntactic representation. If an error occurs in this initial analysis (whether the error is signaled by syntactic or semantic/pragmatic anomaly), the parser then uses whatever information is available, including verb information, to come up with a more acceptable analysis. This difference in timing suggests a different architecture for the sentence processing system. In interactive models, the architecture does not clearly distinguish among components responsible for assigning structure at different levels of representation (lexical, syntactic, semantic). In models such as the garden-path model, there are distinct modules (Fodor, 1983) within the language system, each using its own representational vocabulary (Frazier, 1985). These modules communicate, but in a constrained fashion.

These results are also inconsistent with models of parsing which specify that verb information is used to guide initial syntactic analysis. One such model is Ford et al.'s (1982) lexical guidance model. Ford et al. conducted a study in which subjects were given sentences containing verbs that varied in their lexical preferences, and they were to indicate the interpretation that matched their own. Ford et al. found that subjects reported the interpretation consistent with the verb's lexical bias. However, as already discussed, such a result is consistent with any model of parsing because proponents of all models are agreed that readers ultimately come up with the most plausible interpretation of a sentence. Theoretical disputes arise over the relative timing of various sources of information used to construct a plausible interpretation, and to resolve these disputes, on-line measures of sentence processing must be used. The results from our experiments suggest that, initially, verb information is not used by the parser to guide syntactic analysis, contrary to the proposal of Ford et al.

As argued by Ferreira and Clifton (1986) and Frazier (1985), a processor that computes mandatory and computationally costly representations must do so quickly and efficiently. From this point of view, it may be understandable that the parser does not consult all possible sources of information. A syntactic tree is a prerequisite for semantic interpretation and must be computed anew for every sentence that is encountered (except perhaps for the small class of idioms such as *How are you* and in cases of parallel structures; see Frazier, Taft, Roeper, Clifton, & Ehrlich, 1984). It may be efficient for such a processor to operate so that these computations are performed as simply and efficiently as possible and so that complications are introduced only when absolutely necessary.

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Appendix

Experimental Sentences

1. a. Bill hoped/wrote [that] Jill arrived safely today.
   b. Sue hoped/wrote [that] Iowa elected better people.
   c. He hoped/wrote [that] Sara fired her sister again.
   d. She hoped/wrote [that] the dog forgot to eat lunch.
2. a. He dreamed/doubted [that] the girl needed help now.
   b. She dreamed/doubted [that] birds think like humans.
   c. Joe dreamed/doubted [that] men walk on hot coals.
   d. Ann dreamed/doubted [that] paper floats in hot water.
3. a. Ted realized/recalled [that] cars travel on open road.
   b. Ed realized/recalled [that] wine tastes better now.
   c. He realized/recalled [that] truth follows honest folk.
   d. She realized/recalled [that] Fred hates all cats too.
4. a. Amy decided/learned [that] the sea tastes bad too.
   b. Tom decided/learned [that] history could be fun too.
   c. He decided/learned [that] Paul seemed older today.
   d. She decided/learned [that] air rises if warm or hot.
5. a. John boasted/claimed [that] luggage carries more now.
   b. Tim boasted/claimed [that] land could be scarce now.
   c. He boasted/claimed [that] men forget very little.
   d. He boasted/claimed [that] Ted loved to eat her cake.
6. a. She hinted/warned [that] Harry bought small gifts.
   b. He hinted/warned [that] the cops drive in fast cars.
   c. Jan hinted/warned [that] the fire burned very badly.
   d. Jim hinted/warned [that] guns require a permit here.
7. a. She confirmed/promised [that] money would help him.
   b. He confirmed/promised [that] a gift would be here now.
   c. Al confirmed/promised [that] Mary would write a note.
   d. Pat confirmed/promised [that] Fred drove the car too.
8. a. She confessed/protested [that] boys suggest racy ideas.
   b. He confessed/protested [that] war scares little kids.
   c. Liz confessed/protested [that] Al hates to wash dishes.
   d. Bob confessed/protested [that] Dad cheats his pal too.
9. a. Don wished/forgot [that] kids liked reading books.
   b. Sally wished/forgot [that] gifts excited baby boys.
   c. He wished/forgot [that] Pam needed a ride with him.
   d. She wished/forgot [that] Dan liked to hear her sing.
10. a. John insisted/admitted [that] girls skate fast too.
    b. Sam insisted/admitted [that] teens drink light beer.
    c. He insisted/admitted [that] sex fills his mind now.
    d. She insisted/admitted [that] fish like the water too.
11. a. She pretended/suspected [that] Jack owns credit cards.
    b. He pretended/suspected [that] Jane lifts weights now.
    c. I pretended/suspected [that] cops train the guards too.
    d. Ali pretended/suspected [that] thugs learn to rob men.
12. a. Joe agreed/taught [that] girls marry young nowadays.
    b. Pat agreed/taught [that] boys enjoy soccer games.
    c. He agreed/taught [that] leaves change in the fall.
    d. She agreed/taught [that] ideas amaze the young mind.
13. a. Al asserted/disputed [that] lawyers cheat clients now.
    b. Ed asserted/disputed [that] eggs cause heart problems.
    c. He asserted/disputed [that] issues worry the rich now.
    d. He asserted/disputed [that] ideas affect the new boy.
14. a. Jack revealed/observed [that] news travels fast here.
    b. Jill revealed/observed [that] drugs cause deaths too.
    c. She revealed/observed [that] Mary walks to work now.
    d. He revealed/observed [that] Paul stole the money too.
15. a. Mel prayed/denied [that] John would stop smoking.
    b. Jan prayed/denied [that] Jack would be bad now.
    c. He prayed/denied [that] Keith would play tennis.
    d. She prayed/denied [that] the dog chased the car now.
16. a. Joe figured/advised [that] students cause riots now.
    b. Liz figured/advised [that] tenants avoid high rents.
    c. He figured/advised [that] cars require a tuneup now.
    d. She figured/advised [that] rice costs too much money.

17. a. Sam bragged/guessed [that] Sally saved fifty dollars.
    b. Pam bragged/guessed [that] Chris bakes tasty cakes.
    c. He bragged/guessed [that] chess amuses the new kid.
    d. She bragged/guessed [that] Iowa charges a low tax.
18. a. Don remarked/inferred [that] John likes small rodents.
    b. She remarked/inferred [that] men follow the trend too.
    c. He remarked/inferred [that] the story could look bad.
    d. Ron remarked/inferred [that] she brought the dog back.
19. a. Kim supposed/accepted [that] pens write better now.
    b. He supposed/accepted [that] men smoke to feel better.
    c. Lyn supposed/accepted [that] time moved very slowly.
    d. She supposed/accepted [that] dogs needed the sun too.
20. a. She speculated/maintained [that] rain comes on bad days.
    b. He speculated/maintained [that] Ed laughs at long hair.
    c. Sid speculated/maintained [that] horses chase cats too.
    d. Sal speculated/maintained [that] cattle scare kids away.

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