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The Contributions of Verb Bias and Plausibility to the Comprehension of Temporarily Ambiguous Sentences

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Eyetracking and the self-paced moving-window reading paradigm were used in two experiments examining the contributions of both frequency-based verb biases and the plausibility of particular word combinations to the comprehension of temporarily ambiguous sentences. The temporary ambiguity concerned whether a noun following a verb was its direct object (*The senator regretted the decision immediately.*), or instead the subject of an embedded clause (*The senator regretted the decision had been made public.*). The experiments crossed the plausibility of the temporarily ambiguous noun as a direct object (e.g., *The senator regretted the decision . . .* vs *The senator regretted the reporter . . .*) with verb bias, eliminating a confound present in earlier research and allowing an examination of interactions between the two factors. Unbiased verbs were included as well to evaluate the role of plausibility in the absence of verb bias. The results generally replicated Trueswell, Tanenhaus, and Kello's (1993) finding that verb bias has rapid effects on ambiguity resolution, and showed in addition that verb bias and plausibility interact during comprehension. The results are most consistent with parallel interactive models of language comprehension such as constraint satisfaction models.

Language comprehension requires the rapid integration of incoming words with stored knowledge. Subjective experience suggests that we usually integrate each new word into a constantly evolving interpretation, essentially as soon as we hear or see it. If so, this is an impressive feat, since the relationships

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among the words in a sentence are indeterminate at many points. For example, a sentence beginning with *The historian read the manuscript . . . ,* as in (1) below, can continue in different ways that result in different relationships between *manuscript* and the previous words in the sentence.

1. *The historian read the manuscript . . .*
   a. *. . . during the trip.*
   b. *. . . had been destroyed in the fire.*

In (1a), the historian did read a manuscript; i.e., *the manuscript* is the direct object of the verb *read.* In (1b), however, the historian did not necessarily read a manuscript, but rather read about it in some unspecified source, and *the manuscript* is the subject of an embedded clause rather than the direct object of *read.*

This particular type of ambiguity, which we will call the ''direct object vs sentential complement'' (DO/SC) ambiguity, can be avoided by including the complementizer *that* (e.g., *The historian read that the manuscript had been destroyed in the fire.*). Examination of text corpora show, however, that it is not unusual to omit the complementizer (Elsness, 1984; McDavid, 1964; Thompson & Mulac, 1991). In a sample of approximately 5000 sentences from the University of Pennsylvania's Wall Street Journal corpus (containing the verbs used in the studies to be reported here), *that* was omitted in 33% of the sentences containing embedded sentential complements. Thus, it appears that readers are often faced with resolving these ambiguities.

Temporary ambiguities would seem to present serious problems for comprehenders. Waiting for disambiguating material to arrive before making any interpretation can lead to holding long strings of uninterpreted words in memory when the disambiguation arrives late, as in (2) below.

2. *The historian read the extremely valuable original manuscript written in Dickens' own hand had been destroyed in the fire.*

Pursuing all possible interpretations as equally likely can lead to a different kind of overload. It is clear that we choose one interpretation at least some of the time, since there are times when we realize we have misinterpreted. Indeed, sentences (1b) and (2) above would probably induce such a ''garden-path'' experience in many readers. However, the fact that we notice garden-pathing only occasionally even though temporary ambiguity is fairly common suggests that we do not always choose, or that we are often right when we do.

There have been many studies investigating how the comprehension system handles ambiguity. Some seem to show that subjective impressions are just wrong, i.e. that we garden-path much more often than we realize (e.g., Ferreira & Clifton, 1986; Ferreira & Henderson, 1990; Frazier & Rayner, 1982). This suggests that we generally choose one interpretation, but can usually revise it easily enough when necessary to prevent awareness of any problem. Based on such results, two-stage models of language comprehension have been developed, with a first stage that constructs an initial interpretation based on a subset of the relevant information, and a second stage that revises that interpretation if it turns out to be inconsistent with other information arriving later. The best known of these is the garden-path model developed by Frazier and colleagues (Frazier, 1978, 1987, 1990; Frazier & Clifton, 1996; Frazier & Fodor, 1978). According to this model, the only information used by the first stage in interpreting sentences like those in (1) above is that *read* is a verb and *manuscript* is a noun, and the simplest interpretation of a noun phrase following a verb is as the verb's direct object. Such a system would initially garden-path in all sentences like (1b).

Other studies suggest that people use multiple sources of information interactively to constrain interpretation throughout processing (e.g., Boland, Tanenhaus, Garnsey, & Carlson, 1995; MacDonald, 1994; Pearlmutter & MacDonald, 1995; Trueswell, Tanenhaus, & Garnsey, 1994). Based on these results, Tanenhaus and colleagues (Tabor, Juliano, & Tanenhaus, in press; Trueswell & Tanenhaus, 1994) and MacDonald and colleagues (MacDonald, Pearlmutter, & Seidenberg, 1994b)

have developed sentence comprehension models within a constraint-satisfaction framework. On this view, several types of information become available about each word as soon as it is recognized, and those that are relevant to constraining the developing interpretation begin to do so immediately. In (1b), when the verb *read* is recognized, one type of information that becomes available is the fact that it can appear in several kinds of sentence structures, but is most commonly followed by a direct object. We will refer to such information as ''verb bias''. *Read*'s bias gives more weight to a direct object interpretation of a subsequent noun over other alternatives. Recognizing *read* also provides information about the role in the reading event that its direct object is likely to play, i.e., that it is likely to be the thing being read, the ''theme.'' Once *manuscript* is recognized, its plausibility as a potential theme of *read* can be evaluated. Since *manuscript* is a good theme for *read,* the direct object interpretation is further strengthened. On the constraint satisfaction view, then, (1b) is difficult to understand because multiple sources of information all point toward what turns out to be the wrong interpretation.

In two-stage models, the same factors contribute to (1b)'s difficulty, but they do so at a later revision stage rather than during initial interpretation (Clifton, Speer, & Abney, 1991; Ferreira & Henderson, 1990, 1991; Mitchell, 1989). The second stage of a two-stage system can use the same cues that shape the initial interpretation in constraint-satisfaction models, but only to constrain revision. This approach has been termed ''lexical filtering'' (Clifton et al., 1991; Ferreira & Henderson, 1990; Frazier, 1987; Mitchell, 1987, 1989), as opposed to the ''lexical guidance'' approach of constraint satisfaction models. Both types of models predict that sentences like (1b) are difficult to understand, albeit for somewhat different reasons. The two types of theories make different predictions, however, about sentences like (3).

3. *The bus driver worried the tires were starting to go flat.*

The verb *worried* is followed by embedded clauses more often than by direct objects, and when it is transitive, its direct object must be animate, so *tires* is odd in that role. Thus, information from both the verb and the noun favors an embedded clause interpretation. The constraint-satisfaction approach predicts that (3) should be easy, while the two-stage approach predicts it should be difficult, though not as difficult as (1b), since there are cues available to help revision.

The studies reported here test predictions from the two types of models by examining readers' comprehension of sentences like (1b) and (3). Specifically, we investigate the roles of both the frequency with which a particular verb is used in a particular structure and the plausibility of particular verb–object combinations, and also how the two factors interact during comprehension.

Most studies of sentence comprehension measure reading time, on the assumption that readers slow down when a sentence is difficult to understand. Early studies of the DO/SC temporary ambiguity established that readers slow down on the disambiguating words indicating that a sentence contains an embedded sentential complement (e.g., on *were starting* in (3) above; Frazier & Rayner, 1982). According to the garden-path model, this occurs because readers first interpret the postverbal noun phrase (NP) as a direct object, and then slow down to revise when the disambiguation indicates that was wrong. However, early studies examining the effect of the particular verb in the sentence also found that verb bias modulated the degree of difficulty at the disambiguation (Holmes, 1987; Mitchell & Holmes, 1985). Proponents of the garden-path model argued that verb bias effects obtained in these studies were due to revision rather than initial interpretation (Ferreira & Henderson, 1990; Mitchell, 1989; Rayner & Frazier, 1987), since studies reporting bias effects had used the self-paced moving window paradigm. In this procedure, participants press a button to cause segments of sentences to be presented sequentially, and response times for each segment are used as the comprehension

measure. Because people read more slowly than normal in this procedure, it has been argued that it reflects a combination of initial interpretation and revision, and eyetracking has been argued to provide better measures of initial interpretation processes (e.g., Ferreira & Henderson, 1990). The methodological debate has continued through a series of studies using several variants of the self-paced moving window paradigm (Holmes, Kennedy, & Murray, 1987; Holmes, Stowe, & Cupples, 1989; Mitchell, 1987), eyetracking (Kennedy, Murray, Jennings, & Reid, 1989; Rayner & Frazier, 1987; Schmauder & Egan, submitted; Traxler & Pickering, 1995), or both (Ferreira & Henderson, 1990; Kennison, submitted; Trueswell, Tanenhaus, & Kello, 1993), as well as a few studies using other techniques (lexical decision: Shapiro, Nagel, & Levine, 1993; Watt & Murray, in press; event-related brain potentials: Osterhout, Holcomb, & Swinney, 1994). Some of these studies have shown early effects of verb bias while others have not.

We focus here on recent eyetracking studies. Ferreira and Henderson (1990) found no effects of verb bias on first fixation durations, but did find effects in total reading times, leading them to conclude that verb bias influences reanalysis but not initial interpretation. Trueswell et al. (1993) suggested, however, that a number of factors undermined Ferreira and Henderson's conclusions. First, they argued that the verbs had not been very strongly biased. A second criticism was that the temporarily ambiguous nouns were often not plausible as direct objects. For example, one sentence pair began with either *Ed disputed eggs . . .* or *Ed asserted eggs . . .* , neither of which is plausible when *eggs* is a direct object. Ferreira and Henderson claimed that readers were slow at the disambiguation (e.g., at *cause* in *Ed disputed eggs cause heart problems*.) because they realized they had misinterpreted the preceding noun as a direct object. Perhaps, however, the implausibility of the nouns as direct objects led readers away from the direct object interpretation for both types of verbs, resulting in a decrease in differences between them.

Trueswell et al. conducted a norming study to find verbs that were strongly biased, and constructed sentences with temporarily ambiguous nouns that were plausible direct objects of at least the DO-bias verbs. They found slow first-pass reading times on the disambiguating region in sentences with DO-bias verbs but not SC-bias verbs, suggesting that readers had constructed a sentential complement interpretation by the time they reached the disambiguation in sentences with SC-bias verbs. At the ambiguous noun phrase (NP), first-pass times were nonsignificantly longer after SC-bias verbs than after DO-bias ones, raising the possibility that lexical filtering occurred during the NP and was responsible for the verb effects at the disambiguation. Trueswell et al. offered a different explanation, however, suggesting that slow times on NPs after SC-bias verbs were due to the additional complexity of a sentential complement interpretation over a direct object interpretation (Holmes, 1987).

Trueswell et al. further argued that correlational analyses provided evidence inconsistent with a lexical filtering explanation. They found that a verb's ''*that*-preference'' played a role in determining reading times, starting at the temporarily ambiguous NP. A verb's *that*-preference was the proportion of its SC-containing sentences in their norming study that included an explicit *that.* For their SC-bias verbs, *that*-preference was not correlated with SC-bias strength, so it appeared to be an independent property. Trueswell et al. reasoned that temporarily ambiguous (i.e., *that*-less) sentences might be more difficult when the verb was one that is typically used with *that* present, and they indeed found significant positive correlations between *that*-preference and first-pass reading times at both the temporarily ambiguous NP and the disambiguating region in sentences with SC-bias verbs. They argued that this showed that verb-specific properties came into play too rapidly to be explained by lexical filtering. Juliano and Tanenhaus (1993) reported similar results in

moving window studies, but also found *that*-preferences to be strongly negatively correlated with SC-bias verbs' frequency of occurrence, and suggested that verb familiarity was probably responsible rather than *that*-preference per se (see also Juliano & Tanenhaus, 1994).

In studies combining Trueswell et al.'s materials with an equal number of new items, Kennison (submitted) obtained results intermediate between Ferreira and Henderson's and Trueswell et al.'s. In one eyetracking study, first-pass times were significantly faster at the disambiguating region in ambiguous sentences with SC-bias verbs than in those with DO-bias verbs, but both were slower than their unambiguous counterparts. In addition, first-pass times on the ambiguous postverbal NP were longer after SC-bias verbs than after DO-bias verbs, and more regressive eye movements were initiated from the postverbal NP in ambiguous than in unambiguous sentences after both types of verb. She did not find effects of *that*-preference on reading times, even for the subset of items taken directly from Trueswell et al., and that together with the pattern at the NP led her to conclude that filtering rather than guidance was responsible for the verb bias effects she observed at the disambiguation.

In most studies to date on the DO/SC ambiguity, the primary question has concerned the role of verb bias, and little attention has been paid to the plausibility of the temporarily ambiguous NP as a direct object (see, however Holmes et al., 1989). In Ferreira and Henderson's (1990) materials, many items had NPs that were implausible as direct objects of both the SC-bias and the DO-bias verbs, while in contrast, Trueswell et al. (1993) and Kennison (submitted) used NPs that were plausible direct objects of the DO-bias verbs. All of these studies shared a design in which pairs of SC-bias and DO-bias verbs were yoked in the same sentence frames. The obvious benefit is that word properties such as frequency and length were perfectly controlled at the critical postverbal NP and disambiguating regions, since they were identical across conditions. However, this design also has the drawback that it greatly increases the chance that the plausibility of the main verb/postverbal NP combination will differ across conditions. A sentence set used by both Trueswell et al. and Kennison is given in (4) below, showing that nouns that were plausible as direct objects of DO-bias verbs (e.g., *remembered*) were sometimes considerably less plausible for SC-bias verbs (e.g., *claimed*).

4. a. *Mr. Smith remembered the directions . . .*
   b. *Mr. Smith claimed the directions . . .*

If this was a consistent property of the materials, then plausibility and verb bias both supported a direct object interpretation in items with DO-bias verbs while both cues supported a sentential complement interpretation in items with SC-bias verbs. These studies may thus have overestimated the effects of verb bias, since a combination of verb bias and plausibility may have been responsible for the results.

To assess this possibility, a plausibility rating study was conducted on Trueswell et al.'s materials. Twenty-eight native English speakers rated the plausibility of 20 sentences like those in (4) above, with a period following the postverbal NP to preclude the possibility of a sentential complement interpretation. Sentences with SC-bias verbs were rated significantly less plausible than those with DO-bias verbs (3.4 vs 6.8 on a 7-point scale, where 7 = most plausible; $F_1(1,27) = 406.06$, $MS_e = .40$, $p < .01$; $F_2(1,19) = 141.40$, $MS_e = .81$, $p < .01$). Thus, plausibility and verb bias were indeed confounded in at least the Trueswell et al. materials, and so multiple sources of information converged on a particular interpretation in their studies.

An intuitive naive hypothesis about the relative contributions of verb bias and plausibility to the comprehension of temporarily ambiguous sentences might be that plausibility would be more influential. We necessarily compute the meanings of sentences and have clear intuitions about their plausibility. We do not have similarly clear intuitions about verbs'

biases, nor is it obvious that verb bias need ever be consulted in coming to an interpretation, since it is only probabilistic information. However, a consideration of the nature of the two kinds of information suggests that verb bias might predominate. Because it is a property of a single word (even though it is configural information about the word's tendency to participate in particular kinds of relationships with other words), it might be encoded as part of a verb's lexical representation and as such be retrieved along with other information during word recognition, making it available quite rapidly. Plausibility, in contrast, must be computed across the particular word combinations that appear in a sentence (Tanenhaus, Dell, & Carlson, 1987). As a result, verb bias may be available to the comprehension system more rapidly than plausibility (McElree & Griffith, 1995).

A similar question has been considered in the lexical ambiguity resolution literature, where the results suggest that frequency-based biases predominate. Duffy, Morris, and Rayner (1988), for example, found that a context that strongly constrained an ambiguous word's interpretation toward its less frequent meaning was not sufficient to eliminate its more frequent meaning. When no strong frequency bias was present, however, contextual plausibility did eliminate less plausible alternatives.

The analogy from Duffy et al.'s (1988) results to sentence comprehension is not completely straightforward, however. The frequency-based bias examined by Duffy et al. was relative frequency of alternative meanings for an ambiguous word, and its strong influence might have resulted from its close relation to meaning. Recent work on constraint-based models of sentence comprehension (MacDonald et al., 1994b; Trueswell & Tanenhaus, 1994), however, has explicitly argued that lexical and syntactic ambiguity resolution rely on the same processes, and that many syntactic ambiguities are at least partially reducible to lexical ambiguities. Thus, on this view, the interaction found by Duffy et al. for lexical semantic ambiguity would be expected to appear between verb bias and plausibility in DO/SC sentences.

Two-stage models have not explicitly considered possible relationships between verb bias and plausibility. In versions of two-stage models that include lexical filtering, verb bias can trigger reanalysis within a word or two after the verb, which would be on the temporarily ambiguous NP in the DO/SC ambiguity (Ferreira & Henderson, 1990; Frazier, 1990; Mitchell, 1987, 1989). Similar arguments have been made for the use of plausibility as a trigger for reanalysis (Ferreira & Clifton, 1986; Frazier, 1990; Rayner, Carlson, & Frazier, 1983), suggesting that it too might have effects within a word or two, which would be on the disambiguation for the DO/SC ambiguity. Thus, two-stage models, like constraint-based models and similarly counter to naive intuition, predict that verb bias should predominate in DO/SC sentences. There is no clear prediction from two-stage models, however, about whether the two kinds of information would interact, or instead produce a non-interactive pattern with large effects of verb bias and weaker effects of plausibility.

Several previous studies have examined the combined effects of frequency-based biases of individual words together with some aspect of meaning, either within the sentence or from discourse context (Boland, in press; Britt, 1994; Spivey-Knowlton & Sedivy, 1994; Spivey-Knowlton & Tanenhaus, submitted; Stowe, Tanenhaus, and Carlson, 1990; Trueswell, 1996). Most directly relevant, the combined contributions of verb bias and plausibility to the comprehension of sentences containing DO/SC ambiguities have been examined. Holmes et al. (1989) crossed ambiguous NP plausibility with verb bias in a series of self-paced reading studies and found that readers had difficulty at the disambiguation after DO-bias but not SC-bias verbs, while plausibility appeared to have little or no effect. In contrast, Traxler and Pickering (1995) found plausibility effects in first-pass reading times in an eyetracking study in sentences with SC-bias verbs, but other kinds of verbs were not included, so interactions between

bias and plausibility could not be examined. Kennison (submitted) found verb bias effects in one study (described earlier) but not in another and argued that the difference was due to differences in plausibility between the two studies. In the study showing no verb bias effects, the postverbal NP was plausible as a direct object of both the DO-bias and the SC-bias verbs, leading her to suggest that the apparent verb bias effects in her earlier study were due to combined effects of both cues rather than verb bias alone. However, plausibility was not directly manipulated, and verbs were not as strongly biased in the second study, making the interpretation difficult to evaluate.

Finally, Schmauder and Egan (submitted) directly manipulated the plausibility of the temporarily ambiguous NP as a direct object of both SC-bias and DO-bias verbs in an eyetracking study. The plausibility manipulation was rather subtle (e.g., *The student learned the theorem . . .* vs *The student learned the project . . .*), but plausibility nonetheless influenced first-pass reading times at the disambiguation, although in an unexpected way: First-pass times were significantly faster on the disambiguation when the noun was more plausible as a direct object, when they would be expected to be slower if a plausible NP was more likely to lead to a direct object interpretation. Verb bias influenced the incidence of regressions back from the disambiguation in this study, but not first-pass reading times, which was surprising since a previous study using the same verbs with a different plausibility manipulation had found clear verb bias effects on first-pass times. Plausibility did not interact with verb bias in either measure. Thus, the results showed effects of both verb bias and plausibility, but no interaction between them.

Overall, the existing evidence about how frequency-based structural biases and meaning-based factors combine during comprehension is rather inconsistent. A likely reason is that the two factors were manipulated differently across the studies. It is difficult to assess the relative contributions of factors as different as verb bias and plausibility to comprehension when there is no common metric ensuring that they are manipulated equally strongly in a particular set of materials. In the studies presented below, materials spanning as wide a range as possible in both factors were created. To evaluate plausibility effects at multiple levels of verb bias, conditions with strongly biased verbs and also with unbiased verbs were included. The latter allow an examination of plausibility effects in the absence of verb bias and provide a comparison with Duffy et al.'s (1988) conditions with ambiguous words whose alternative meanings had equal frequencies. Highly plausible and highly implausible NPs were also included, and plausibility levels were equated for each verb type, allowing us to determine whether the two factors interact and more specifically to test the prediction that plausibility will have little effect when verbs are strongly biased, but clear effects when verbs are unbiased.

EXPERIMENT 1

An eyetracking study was conducted to investigate the roles of verb bias and plausibility in the comprehension of sentences with the DO/SC temporary ambiguity. DO-bias and SC-bias verbs were included, as in previous studies, and a third type of verb, called equibias (EQ-bias) here, was added. By analogy to lexical ambiguity resolution results, the prediction for DO/SC ambiguities resolved with a sentential complement continuation is that: (1) plausibility will not eliminate difficulty for DO-bias verb cases, (2) SC-bias verb cases will not be difficult, again regardless of plausibility, and (3) plausibility will have a strong effect for EQ-bias verb cases, such that a NP that is not plausible as a direct object should eliminate difficulty, but a NP that is plausible as a direct object should create difficulty.

Method

Participants

Seventy-eight University of Illinois students (36 males, 42 females; mean age 21) participated for payment. All had normal, un-

corrected vision and were native speakers of English. Sixteen of the 78 participants were omitted from the analyses, either because of excessive trackloss or a high error rate (greater than 15%) on comprehension questions asked after the sentences, leaving 62 participants.

Materials and Design

A norming study was conducted to determine the structural biases of 100 verbs that can take sentential complements (Connine, Ferreira, Jones, Clifton, & Frazier, 1984). A separate group of 108 participants completed sentence fragments consisting of a proper name followed by one of the 100 verbs (e.g., *Debbie remembered* _____). The completions were coded by hand, and percentages of the total number of responses for each verb were computed for three categories: (1) completions containing direct objects, (2) completions containing embedded sentential complements, separately by whether or not *that* was present, and (3) other types of structures (infinitives, prepositional phrases, etc.). The full set of 100 verbs and details of the materials, design, and procedures for the norming study are described in Garnsey, Lotocky, Pearlmutter, & Myers (in preparation).

Verbs were classified as SC-bias if they were used at least twice as often with an embedded sentential complement as with a direct object, while the reverse was true for verbs classified as DO-bias. Verbs were classified as EQ-bias if they occurred approximately equally often with direct objects and with sentential complements (difference not greater than 15%). Using these criteria, 16 verbs of each type were chosen, for a total of 48 verbs.[1] Approximately half of the verbs in the DO-bias and SC-bias categories were also used by Ferreira and Henderson (1990) or by Trueswell et al. (1993), or both. Three of the 16 SC-bias verbs and 2 of the 16 DO-bias verbs were in the opposite category from Ferreira and Henderson's classification, and 3 of the EQ-bias verbs had been classified by them as DO-bias. Our classifications agreed with Trueswell et al.'s for the verbs in common across the studies.

The three sets of verbs did not significantly differ in length ($F = 2$) or frequency of occurrence (Francis & Kucera, 1982; $F = 1$), but did differ in SC-bias ($F(2,45) = 29.38$, $MS_e = 276$, $p < .01$), DO-bias ($F(2,45) = 91.26$, $MS_e = 173$, $p < .01$), and *that*-preference ($F(2,45) = 14.88$, $MS_e = 144$, $p < .01$), which was measured in the same way for our norming study as in Trueswell et al. The properties of the 48 verbs are summarized in Table 1 and the norming results for each verb are given in Appendix A.

One criterion for choosing verbs was that both a very plausible and a very implausible direct object noun had to be found for them, which ruled out using triples of SC-, DO-, and EQ-bias verbs in the same sentence frames. Thus, a separate subject NP (always *the* plus an adjective–noun or noun–noun combination) and two direct object NPs (always *the* plus a noun) were chosen for each verb, such that one of the object NPs was plausible as a direct object and the other was not. Plausibility was determined in a norming study in which a separate group of 154 participants rated sentences like those in (5) on a 7-point scale (7 = very plausible). Each sentence was composed of the ambiguity-producing verb (e.g., *regretted*) with its subject NP (*the senior senator*) and either a plausible or implausible direct object (*the decision* or *the reporter*, respectively).

5. a. *The senior senator regretted the decision.*
   b. *The senior senator regretted the reporter.*

The materials were modified and renormed until they met the criterion that the difference

[1] It was subsequently discovered that two of the EQ-bias verbs had been miscoded in the verb bias norming study. One (*acknowledged*) actually fit the criteria for DO-bias verbs, and the other (*estimated*) nearly did. All analyses were conducted using both the original verb classifications and reclassifying these two verbs. There were some small differences between the results of the two sets of analyses. To maintain the balance of the design, results will be reported for the original classifications, and those cases where the two analyses differed will be noted.

TABLE 1

PROPERTIES OF VERBS USED IN THE EXPERIMENTS

	Frequency	Length	SC-bias	DO-bias	*that*-preference
DO-bias verbs	146	8.3	14%	75%	89%
EQ-bias verbs	178	7.6	36%	38%	71%
SC-bias verbs	128	7.7	59%	12%	67%

in ratings between the plausible and implausible direct object version for each verb was at least 2.5 on the 7-point scale. A separate group of 52 participants rated sentence fragments like those in (6) as beginnings of sentences, to assess whether the verb bias and plausibility manipulations had any effect on the subject-of-an-embedded-clause interpretation of the postverbal NP.

6. a. *The senior senator regretted that the decision was . . .*
   b. *The senior senator regretted that the reporter was . . .*

The frequencies, lengths, and ratings of the nouns are summarized in Table 2, and plausibility ratings are given for each item in Appendix B. The sets of nouns did not differ significantly in length (Fs < 1 except for the effect of plausibility: $F(1,45) = 2.58$, $MS_e = 2$, $p > .1$) or frequency of occurrence (Fs < 2). The rated plausibility as a direct object differed significantly between the plausible and implausible nouns ($F(1,45) = 1406.19$, $MS_e = .22$, $p < .01$), but did not differ across verb type ($F < 2$). Not surprisingly, ratings for the unambiguous sentential complement versions of the sentences (as in 6 above) did differ across verb type ($F(2,45) = 8.33$, $MS_e = .45$, $p < .01$) as well as between the plausible and implausible noun sets ($F(1,45) = 5.95$, $MS_e = .23$, $p < .05$). The verb effect was due to higher ratings for sentences with SC-bias verbs; i.e., sentences containing embedded clauses were rated higher when they contained verbs that were more likely to be used that way (see Table 2). The plausibility effect arose because nouns that were rated as better direct objects were also rated as better subjects of embedded clauses (6.1 vs 5.7). Thus, any effects of plausibility on reading times cannot be attributed entirely to the plausibility of the temporarily ambiguous NP as a direct object, since its plausibility as the subject of an embedded clause may also play some role. However, since differences in plausibility as an embedded subject were much smaller than those in plausibility as a direct object (.4 vs 3.6, on average), any effects of plausibility on reading times are likely to be due primarily to the latter. Crucially, there were no interactions between verb bias and either type of plausibility rating in the materials (Fs < 1).

TABLE 2

PROPERTIES OF AMBIGUOUS NOUNS USED IN THE EXPERIMENTS

	Plausible				Implausible			
	Frequency	Length	Direct object rating	Clause subject rating	Frequency	Length	Direct object rating	Clause subject rating
DO-bias verbs	132	6.3	6.5	5.7	166	5.5	2.9	5.4
EQ-bias verbs	106	6.5	6.5	5.9	62	6.3	2.9	5.7
SC-bias verbs	67	6.7	6.2	6.3	47	6.3	2.6	6.1

Four sentence versions were constructed for each of the 48 verbs. The subject NPs used in the plausibility norming study were retained, since plausibility of the postverbal NP as a direct object depends partly on the subject. The subject NP was followed by the ambiguity-producing verb in the past tense, which was then followed by *that* in the unambiguous versions of each sentence. Next came the NP that was either plausible or implausible as a direct object of the verb. A disambiguating auxiliary verb followed the NP and was in turn followed by four more words. The disambiguating auxiliary verb and the following word were identical but the last three words of the sentences were allowed to differ between the implausible and plausible conditions so that all of the sentences ended sensibly. Comprehension questions that required understanding the sentences but did not call attention to the experimental manipulations were also constructed for each item. Half of these required a ''yes'' answer and half a ''no'' answer. An example item is shown in (7), along with its comprehension questions, where *the decision* in (7a) is plausible as a direct object of *regretted* and *the reporter* in (7b) is not. All 48 sentence sets are given in Appendix B.

7. a. *The senior senator regretted (that)* the decision *had ever been made public.*
   Had the decision been made public?
   b. *The senior senator regretted (that)* the reporter *had ever seen the report.*
   Did the reporter know something?

Four 110-item lists were created, each containing one version of each of the 48 experimental items and 62 filler items. Ten additional practice items were also constructed, and all fillers and practice items had comprehension questions. Each list contained exactly one version of each experimental sentence and equal numbers of items in each condition. Experimental items and fillers were pseudorandomly interleaved such that items were in the same order across lists, and all participants saw the same order.

Of the fillers, 32 were part of unrelated experiments, and in 8 of these, the subject and verb failed to agree, making the sentence ungrammatical (e.g., *The mistake in the programs were disastrous for the small company.*). The remaining 30 fillers had a variety of structures, including transitives (i.e., sentences with direct objects), intransitives, and infinitives, some with relative clauses. Some examples are given in (8), along with their comprehension questions.

8. a. *The paintings at the art museum were in storage for several years.*
   Were the paintings being shown?
   b. *The ball players from the club were volunteering to teach little league.*
   Were the ball players teaching kids?
   c. *The willow tree that was shaded by the oak hadn't grown in a while.*
   Had the willow tree stopped growing?
   d. *John's mother anticipated the flimsy excuse as soon as he opened his mouth.*
   Was John able to fool his mother?

The experimental items were the only sentences with a sentential complement structure, comprising 44% of the items in a list. Thirty-one (28%) of the fillers (including some of the 32 items that were part of other experiments) had a direct object NP immediately following the main verb, and in 19 of these (17%), the main verb could take a sentential complement (e.g., 9d), like the verbs in the experimental items. The fact that 72% of the stimuli with sentential-complement-taking verbs contained such complements raises the possibility that participants might develop an experiment-specific expectation for such sentences. While such an expectation might lead to overall greater ease than usual for sentences with sentential complements, there is no reason to expect it to change the way readers use verb bias and plausibility information. Indeed, for any such expectation to affect the use of the two cues at typical reading rates, readers would need rapid access to both types of information and an ability to combine them

quickly, which is not consistent with the claim in two-stage models that such information is not rapidly available.

Procedure

Stimuli were presented on a Conrac 1000 color monitor such that four characters subtended 1° of visual angle, and eye movements were monitored using a Fifth Generation Stanford Research Institute Dual Purkinje Eyetracker interfaced with an IBM-compatible PC. Viewing was binocular but only the right eye was monitored, with vertical and horizontal eye position sampled every millisecond. A bite bar was prepared for each participant to minimize head movements, and the room was slightly dimmed to provide a comfortable viewing environment. The eyetracker was calibrated for each participant at the start of the session, and again after every break. Participants took breaks as needed, in addition to scheduled breaks after the practice trials and after every 30 trials thereafter. The entire experiment lasted approximately 40 min.

Each trial began with a trial number at the left side of the screen, and participants were instructed to fixate the number and then press a button to indicate they were ready for a sentence. Each sentence appeared in its entirety across one line on the screen, along with a fixation box to the right of the end of the sentence. Participants were instructed to read the sentence at their own pace and then to fixate the box when they were done, before pushing a button to indicate that they were ready for a comprehension question. The fixation box helped to minimize the occurrence of large regressive eye movements back to the left side of the screen before the end-of-sentence button press. Comprehension questions were presented after every sentence, and participants answered by pressing one of two hand-held buttons, after which feedback was given.

Results

Trials on which there was trackloss involving a region of interest were discarded, resulting in an overall loss of 13% of the data. The incidence of trackloss did not differ across experimental conditions (13% for each verb type, 12% for ambiguous sentences vs 13% for unambiguous ones, and 14% for sentences with plausible nouns vs 12% for those with implausible nouns; all Fs < 2).

Trials with incorrect responses to the comprehension questions were also eliminated from reading time analyses. The overall error rate was 4%, with the fewest questions missed after sentences with EQ-bias verbs (3%), next fewest after DO-bias verbs (4%), and most after SC-bias verbs (5%; $F_1(2,122) = 3.67$, $MS_e = 116$, $p < .05$; $F_2(2,45) < 2$). Neither plausibility (4% vs 5%; $F_1(1,61) = 2.56$, $MS_e = 100$, $p > .1$; $F_2 < 2$) nor ambiguity (5% vs 4%; Fs < 2) significantly affected accuracy, but there was an interaction among all three factors ($F_1(2,122) = 5.00$, $MS_e = 94$, $p < .01$; $F_2(2,45) = 3.14$, $MS_e = 40$, $p < .05$).

Readers often skip short, high frequency words in sentences (Rayner & Pollatsek, 1989), making it difficult to analyze reading times for such words, so they are commonly grouped with other words into analysis regions. Here, function words were grouped with the following word, except that *that* was analyzed separately when it was present. Analysis regions are indicated in (9) below. The two critical regions of the sentence, the temporarily ambiguous NP (*the decision*) and the disambiguation (*had ever*), each consisted of two words.

9. *The senior senator|regretted|(that)|the decision|had ever|been made|public.*

Both first-pass and total reading times will be presented. First-pass times are the sum of all fixations made on a region before leaving it the first time it is read, while total times are the sum of all fixations on a region at any time, including rereading (Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). To facilitate comparisons to Ferreira and Henderson's (1990) results, first fixation durations on the disambiguating region are also presented. Finally, the percentage of trials on which the first pass on the disambiguating region ended with a regression is reported, since readers

sometimes look back when they have difficulty, rather than or in addition to slowing down (Altmann, Garnham, & Dennis, 1992; Rayner et al., 1989; Schmauder & Egan, submitted). Mean reading times for each region were submitted to both participant- and item-based 2 (ambiguity) $\times$ 2 (plausibility) analyses of variance (Clark, 1973). Since comparisons across verb type involved completely different stimuli, separate ANOVAs were conducted for each verb type, except that the main verb and *that* were analyzed across verb type.

Even within each verb type, one comparison involved different words. The noun in the temporarily ambiguous NP necessarily differed between plausible and implausible versions of a sentence. Although the plausible and implausible nouns did not differ significantly in length, they were not ideally matched (see Table 2), since it was not possible to do so and still maintain adequate control over plausibility. To minimize the impact of variability in word length, reading times were adjusted for length. For each participant, a regression equation was derived, using every region read during the experiment, which predicted reading times from region length (see Ferreira & Clifton, 1986; Trueswell et al., 1994). Separate regression equations were derived for first-pass and total reading times, and in each case, unfixated regions were excluded. The predicted values were then subtracted from the actual time spent on each region, generating residual reading times with length effects removed. Residual reading times beyond 2.5 *SD* above or below a participant's mean time on each region were replaced with the 2.5 *SD* cutoff value, affecting 3% of the data (Forster & Chambers, 1973), and analyses were performed on these trimmed residual times. Both uncorrected times (also trimmed at 2.5 *SD* with replacement) and length-corrected residuals are given in Tables 3 (first-pass times) and 4 (total times). Condition means given in the text are trimmed reading times before length correction, but the accompanying statistics were calculated using length-corrected residuals (given in the tables).

Results will be described first for the disambiguating region of the sentences and then for other critical sentence regions. Figures 1 (first-pass times) and 2 (total times) show ambiguity effects at the disambiguation and at the ambiguous NP, obtained by subtracting reading times in unambiguous conditions from their ambiguous counterparts.

First-Pass Reading Times

The disambiguation (Fig. 1a). More first-pass time was spent on the disambiguating region in ambiguous than in unambiguous sentences only for DO-bias verbs (365 vs 332 ms; $F_1(1,61) = 5.88$, $MS_e = 8369$, $p < .05$; $F_2(1,15) = 5.00$, $MS_e = 2622$, $p < .05$). There was no similar overall ambiguity effect in sentences with other verb types (SC-bias: 336 vs 336 ms; EQ-bias: 322 vs 325 ms; all Fs < 1).[2] Figure 1a shows that the ambiguity effect in sentences with DO-bias verbs was somewhat larger when the NP was plausible as a direct object (379 vs 338 ms; $F_1(1,61) = 5.59$, $MS_e = 7656$, $p < .05$; $F_2(1,15) = 5.00$, $MS_e = 3441$, $p < .05$) than when it was implausible (350 vs 326 ms; $F_1(1,61) = 1.17$, $MS_e = 9791$, $p > .1$; $F_2(1,15) = 1.76$, $MS_e = 1611$, $p > .1$), but not enough so to produce an interaction between plausibility and ambiguity for these items (Fs < 1). Thus, readers had difficulty at the disambiguation in sentences where a NP following a DO-bias verb turned out not to be a direct object, even when it would not have made a plausible direct object. There was no effect of ambiguity at the disambiguation in sentences with SC-bias verbs (plausible: 331 vs 329 ms; implausible: 340 vs 343 ms; all Fs < 1), so readers had no difficulty when a NP following a SC-bias verb turned out not to be a direct object, even when it would have made a plausible direct object. There were also no significant main effects of plausibility

[2] The first disambiguating word (e.g., *had*) was skipped equally often in ambiguous and unambiguous (34% vs 35%) sentences (Fs < 2). The second disambiguating word was skipped slightly more often in ambiguous sentences than in unambiguous ones (41% vs 38%; $F_1(1,61) = 3.84$, $MS_e = 906$, $p = .05$; $F_2 < 2$).

TABLE 3

EXPERIMENT 1 FIRST-PASS READING TIMES

Sentence region	Plausible			Implausible		
	Ambiguous	Unambiguous	Ambiguity effect	Ambiguous	Unambiguous	Ambiguity effect
DO-bias items						
Main V (. . . *wrote*)	326 (−4)	313 (−13)	13 (9)	311 (−11)	298 (−26)	13 (15)
Complementizer (*that*)	—	238 (−4)	—	—	254 (8)	—
Ambig NP (*the interview/painting*)	350 (−16)	345 (−23)	5 (7)	364 (12)	320 (−34)	44 (46)
Disambiguation (*had been*)	379 (21)	338 (−16)	41 (37)	350 (−7)	326 (−27)	24 (20)
Post-disambiguation	385 (42)	388 (34)	−3 (8)	406 (36)	390 (24)	16 (12)
EQ-bias items						
Main V (. . . *regretted*)	315 (−4)	312 (−7)	3 (3)	303 (−11)	289 (−26)	14 (15)
Complementizer (*that*)	—	239 (−3)	—	—	243 (3)	—
Ambig NP (*the decision/reporter*)	367 (−4)	349 (−23)	18 (19)	358 (−10)	340 (−28)	18 (18)
Disambiguation (*had ever*)	336 (−12)	321 (−29)	15 (17)	307 (−47)	329 (−22)	−22 (−25)
Post-disambiguation	414 (67)	407 (60)	7 (7)	399 (48)	394 (34)	5 (14)
SC-bias items						
Main V (. . . *confessed*)	286 (−29)	290 (−28)	−4 (−1)	290 (−25)	277 (−38)	13 (13)
Complementizer (*that*)	—	228 (−17)	—	—	238 (−5)	—
Ambig NP (*the robbery/vault*)	361 (−14)	336 (−43)	25 (29)	355 (−11)	338 (−31)	17 (20)
Disambiguation (*had been . . .*)	331 (−27)	329 (−30)	2 (3)	340 (−23)	343 (−15)	−3 (−8)
Post-disambiguation	390 (39)	402 (41)	−12 (−2)	402 (61)	399 (54)	3 (7)

Note. Numbers in parentheses are residuals after length correction. See text.

for any of the verb types (SC-bias: 330 vs 342 ms, Fs < 1; DO-bias: 359 vs 338 ms; $F_1(1,61) = 2.50$, $MS_e = 8639$, $p > .1$; $F_2(1,15) = 2.70$, $MS_e = 2060$, $p > .1$; EQ-bias: 329 vs 318 ms; $F_1 < 2$; $F_2(1,15) = 3.02$, $MS_e = 1253$, $p > .1$), but for EQ-bias verbs plausibility and ambiguity interacted ($F_1(1,61) = 8.37$, $MS_e = 8312$, $p < .01$; $F_2(1,15) = 7.04$, $MS_e = 948$,

TABLE 4

EXPERIMENT 1 TOTAL READING TIMES

Sentence region	Plausible			Implausible		
	Ambiguous	Unambiguous	Ambiguity effect	Ambiguous	Unambiguous	Ambiguity effect
DO-bias items						
Main V (. . . *wrote*)	417 (−8)	372 (−38)	45 (46)	415 (11)	367 (−40)	48 (49)
Complementizer (*that*)	—	287 (4)	—	—	282 (−5)	—
Ambig NP (*the interview/painting*)	446 (−20)	412 (−62)	34 (42)	456 (7)	394 (−57)	62 (64)
Disambiguation (*had been*)	518 (65)	416 (−36)	102 (101)	451 (−3)	412 (−35)	39 (32)
Post-disambiguation	513 (83)	495 (47)	18 (35)	494 (25)	478 (4)	16 (21)
EQ-bias items						
Main V (. . . *regretted*)	379 (−18)	352 (−38)	27 (20)	382 (−5)	347 (−40)	35 (35)
Complementizer (*that*)	—	253 (−22)	—	—	277 (−4)	—
Ambig NP (*the decision/reporter*)	440 (−36)	407 (−67)	33 (31)	463 (−8)	418 (−53)	45 (45)
Disambiguation (*had ever*)	444 (4)	406 (−36)	38 (40)	403 (−46)	431 (−15)	−28 (−31)
Post-disambiguation	517 (81)	506 (74)	11 (7)	531 (86)	516 (60)	15 (26)
SC-bias items						
Main V (. . . *confessed*)	356 (−32)	339 (−54)	17 (22)	370 (−21)	326 (−64)	44 (43)
Complementizer (*that*)	—	244 (−39)	—	—	267 (−10)	—
Ambig NP (*the robbery/vault*)	437 (−44)	383 (−105)	54 (61)	433 (−37)	389 (−81)	44 (44)
Disambuguation (*had been . . .*)	405 (−46)	398 (−59)	7 (13)	425 (−40)	417 (−40)	8 (0)
Post-disambiguation	492 (46)	473 (21)	19 (25)	489 (61)	507 (70)	−18 (−9)

Note. Numbers in parentheses are residuals after length correction. See text.

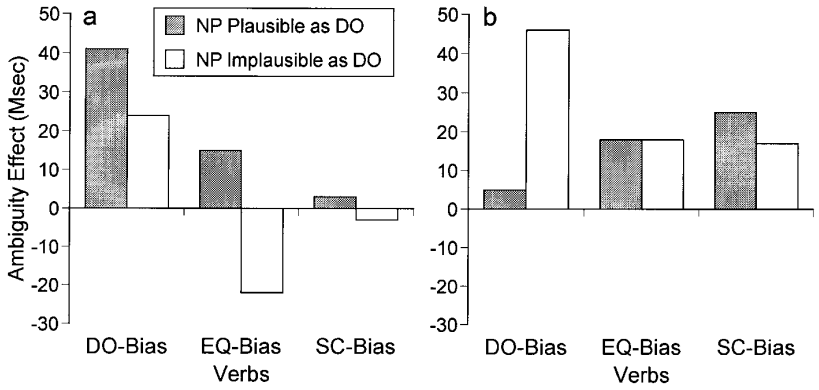

FIG. 1. Ambiguity effects (ambiguous reading time minus unambiguous reading time) at the disambiguating region (a) and in the temporarily ambiguous NP (b) in first-pass reading times in Experiment 1.

$p < .05$), such that ambiguous sentences with plausible NPs were marginally slower than unambiguous sentences by participants (336 vs 321 ms; $F_1(1,61) = 3.78$, $MS_e = 8162$, $p < .1$; $F_2(1,15) = 1.79$, $MS_e = 1524$, $p > .1$), while ambiguous sentences with implausible NPs were significantly faster than unambiguous ones by participants (307 vs 329 ms; $F_1(1,61) = 5.18$, $MS_e = 7520$, $p < .05$; $F_2(1,15) = 2.74$, $MS_e = 1464$, $p > .1$).[3] Faster times in the ambiguous than in the unambiguous condition when the NP was implausible were not expected, and this ''reverse ambiguity effect'' will be explored further in the discussion.

First fixations showed a pattern similar to the first-pass times for DO- and SC-bias verbs: First fixations were longer in ambiguous than in unambiguous sentences only for DO-bias verbs (237 vs 225 ms; $F_1(1,61) = 4.82$, $MS_e = 1563$, $p < .05$; $F_2(1,15) = 3.20$, $MS_e = 439$, $p < .1$; SC-bias: 232 vs 229 ms; EQ-bias: 230 vs 231 ms; Fs < 1). Unlike first-pass times, there were no reliable effects of plausibility on first fixations on this region (all Fs < 2 except for EQ-bias verbs, where the plausibility main effect approached significance by participants: 234 vs 226 ms; $F_1(1,61) = 2.97$, $MS_e = 1290$, $p < .1$; $F_2(1,15) = 2.20$, $MS_e = 317$, $p > .1$), nor were there any interactions between plausibility and ambiguity (all Fs < 1).

The percentage of first passes on the disambiguation ending with a regression was not significantly greater in ambiguous than in unambiguous sentences for any of the verb types (SC-bias: 7% vs 5%, Fs < 2; EQ-bias: 8% vs 6%, Fs < 2; DO-bias: 11% vs 7%, $F_1(1,61) = 2.11$, $MS_e = 345$, $p > .1$; $F_2 < 2$). There was, however, a significant effect of plausibility on the percentage of regressions, but only in sentences with DO-bias verbs: More regressions were made after plausible than after implausible NPs (11% vs 6%, $F_1(1,61) = 4.66$, $MS_e = 251$, $p < .05$; $F_2(1,45) = 6.27$, $MS_e = 35$, $p < .05$). There was no similar plausibility effect for the other verbs (SC-bias: 6% vs 6%; EQ-bias: 8% vs 6%; all Fs < 2), nor were there any interactions between plausibility and ambiguity for any verb type (all Fs < 2).

In sum, both first-pass times and first fixations showed that the amount of difficulty readers had at the disambiguation was influenced by verb bias, while plausibility affected first-pass times in sentences with EQ-bias verbs and the incidence of regressions in sentences with DO-bias verbs. Plausibility had no effect on any measure in sentences with SC-bias verbs, nor on first fixations in any condition.

[3] In the analysis where the two miscoded EQ-bias verbs were reclassified, the ambiguity effect in sentences with EQ-bias verbs and plausible NPs reached significance by participants ($F_1(1,61) = 6.27$, $MS_e = 5591$, $p < .05$; $F_2 < 2$).

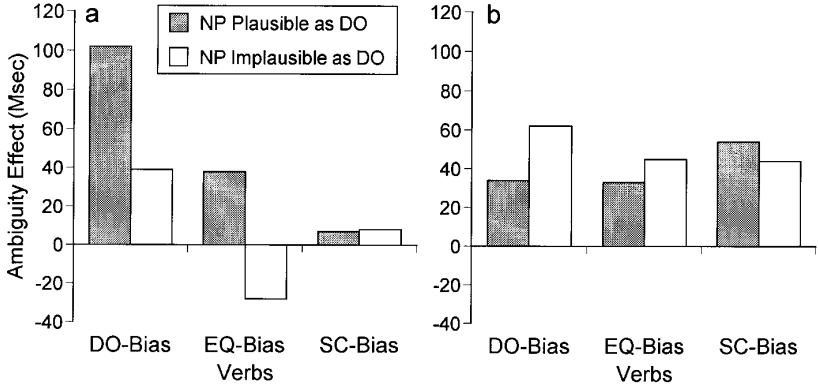

FIG. 2. Ambiguity effects (ambiguous minus unambiguous) at the the disambiguating region (a) and at temporarily ambiguous NP (b) in total reading times in Experiment 1.

The temporarily ambiguous NP (Fig. 1b). According to a lexical filtering account of verb bias effects, reading times should be longer at the point where filtering takes place. Thus, if reading times were fast at the disambiguation in sentences with SC-bias verbs, they should have been slower at some earlier point when verb bias became available and triggered revision. For these sentences, the prediction is that differences between ambiguous and unambiguous sentences in first-pass reading times on the NP should be largest in sentences with SC-bias verbs, since filtering could begin at the NP in those sentences.

In fact, the size of the overall ambiguity effect at the NP was quite similar after SC-bias verbs (358 vs 337 ms) and DO-bias verbs (357 vs 333 ms). It was slightly larger for DO-bias verbs, for which it was reliable by both participants and items ($F_1(1,61) = 6.12$, $MS_e = 7563$, $p < .05$; $F_2(1,15) = 9.48$, $MS_e = 1082$, $p < .01$), while for SC-bias verbs it was reliable only by items ($F_1(1,61) = 2.16$, $MS_e = 9806$, $p > .1$; $F_2(1,15) = 6.30$, $MS_e = 1434$, $p < .05$). A similar overall difference in sentences with EQ-bias verbs did not reach significance (363 vs 345 ms; $F_1 < 2$, $MS_e = 8189$; $F_2(1,15) = 2.45$, $MS_e = 2279$, $p > .1$).[4] So, overall ambiguity effects at the NP were fairly similar after all verb types.

Plausibility, in contrast, did affect reading times on the NP differently across the verb types. For DO-bias verbs only, the interaction between plausibility and ambiguity at the NP approached significance by participants ($F_1(1,61) = 3.49$, $MS_e = 6064$, $p < .1$; $F_2(1,15) = 2.87$, $MS_e = 2076$, $p > .1$; Fs for other verbs < 1),[5] because implausible ambiguous NPs were read more slowly than their unambiguous counterparts (364 vs 320 ms; $F_1(1,61) = 10.58$, $MS_e = 6142$, $p < .01$; $F_2(1,15) = 13.27$, $MS_e = 1201$, $p < .01$), but plausible ambiguous NPs were not (350 vs 345 ms; Fs < 1). Within just the ambiguous conditions with DO-bias verbs, the implausible NP was read more slowly than the plausible NP, significant by participants (364 vs 350 ms; $F_1(1,61) = 6.60$, $MS_e = 5095$, $p < .05$; $F_2(1,15) = 2.30$, $MS_e = 2443$, $p > .1$). There were no similar effects of plausibility at the NP for other verbs, neither main effects nor interactions with ambiguity (all Fs < 1).

[4] The word *the* in the NP was skipped more often in ambiguous sentences than in unambiguous ones (59% vs 49%; $F_1(1,61) = 13.20$, $MS_e = 1461$, $p < .01$; $F_2(1,45) = 22.42$, $MS_e = 225$, $p < .01$). As Trueswell et al. pointed out, readers are generally less likely to skip *the* in unambiguous sentences because it is preceded by *that,* which is itself often skipped, and readers are unlikely to skip two function words in a row.

[5] When the two miscoded verbs were reclassified as DO-bias, the interaction between plausibility and ambiguity for DO-bias verbs just reached significance by participants ($F_1(1,61) = 3.88$, $MS_e = 5900$, $p = .05$; $F_2(1,17) = 2.28$, $MS_e = 1972$, $p > .1$).

Earlier in the sentence. First-pass times on the main verb were longer in ambiguous sentences than in unambiguous ones (305 vs 297 ms; $F_1(1,61) = 6.84$, $MS_e = 3027$, $p < .05$; $F_2(2,94) = 4.54$, $MS_e = 1171$, $p < .05$). Since the ambiguous and unambiguous sentences were still identical at the verb, this difference was probably due to parafoveal preview of the following word, which differed between ambiguous and unambiguous sentences (*the* vs *that*). There was also a main effect of verb bias by participants ($F_1(2,122) = 4.21$, $MS_e = 4830$, $p < .05$; $F_2 < 2$), such that DO-bias verbs were read slowest and SC-bias verbs fastest (SC-bias, 286 ms; EQ-bias, 305 ms; DO-bias, 312 ms).

In the unambiguous sentences, the complementizer *that* was skipped approximately equally often after all of the verbs (SC-bias, 42%; EQ-bias, 43%; DO-bias, 47%; Fs < 1). When it was fixated, first-pass time did not differ significantly across verb type (SC-bias, 233 ms; EQ-bias, 241 ms; DO-bias, 246 ms; Fs < 2).[6]

In sum, both first-pass times and first fixation durations showed that readers had difficulty at a disambiguation toward a sentential complement interpretation in sentences with DO-bias verbs but not in sentences with SC-bias verbs. The plausibility of the temporarily ambiguous NP as a direct object did not affect first-pass times at either the NP or the disambiguation in sentences with SC-bias verbs, but did affect first-pass times on the NP after DO-bias verbs and on the disambiguation after EQ-bias verbs. Plausibility also affected the likelihood of ending the first pass on the disambiguating region with a regression in sentences with DO-bias verbs.

Total Reading Times

The disambiguation (Fig. 2a). The overall pattern in total times was similar to first-pass times. There were no significant differences among conditions in sentences with SC-bias verbs (plausible, 405 vs 398 ms; implausible, 425 vs 417 ms; all Fs < 1). In sentences with DO-bias verbs, more total time was spent reading the disambiguation in ambiguous than in unambiguous sentences (485 vs 414 ms; $F_1(1,61) = 14.46$, $MS_e = 17469$, $p < .01$; $F_2(1,15) = 5.51$, $MS_e = 14270$, $p < .05$). Unlike first-pass times, total times also showed an interaction between plausibility and ambiguity in sentences with DO-bias verbs, reliable by participants ($F_1(1,61) = 6.59$, $MS_e = 13785$, $p < .05$; $F_2(1,15) = 2.86$, $MS_e = 7130$, $p > .1$), which arose because times were significantly slower in ambiguous than in unambiguous sentences when the NP was plausible (518 vs 416 ms; $F_1(1,61) = 17.40$, $MS_e = 18574$, $p < .01$; $F_2(1,15) = 6.56$, $MS_e = 13654$, $p < .05$), but not when the NP was implausible (451 vs 412 ms; Fs < 2). Sentences with EQ-bias verbs showed the same interaction between plausibility and ambiguity as first-pass times ($F_1(1,61) = 7.58$, $MS_e = 17095$, $p < .01$; $F_2(1,15) = 4.13$, $MS_e = 4238$, $p < .1$), and it again arose because people spent marginally more time on the disambiguation in ambiguous sentences than in unambiguous ones when the NP was plausible as a direct object (444 vs 406 ms; $F_1(1,61) = 3.03$, $MS_e = 31904$, $p < .1$; $F_2(1,15) = 3.97$, $MS_e = 3340$, $p < .1$), and the pattern was reversed when the NP was implausible as a direct object (403 vs 431 ms; $F_1(1,61) = 3.24$, $MS_e = 12135$, $p < .1$; $F_2(1,15) = 1.04$, $MS_e = 4982$, $p > .1$).[7]

The temporarily ambiguous NP (Fig. 2b). More total time was spent on the NP in ambiguous sentences than in unambiguous ones for each of the three types of verbs (SC-bias, 435 vs 386 ms; $F_1(1,61) = 8.35$, $MS_e = 14577$, $p < .01$; $F_2(1,15) = 13.63$, $MS_e = 2794$, $p < .01$; DO-bias, 451 vs 403 ms; $F_1(1,61) = 12.36$, $MS_e = 15010$, $p < .01$; $F_2(1,15) = 7.24$, $MS_e = 6921$, $p < .05$; EQ-bias, 452 vs

[6] Four participants were dropped from the analyses of *that* because there were some conditions in which they never fixated it.

[7] As in first-pass times, the ambiguity effect for the plausible conditions with EQ-bias verbs reached significance by participants in the analysis reclassifying the two miscoded verbs ($F_1(1,61) = 4.25$, $MS_e = 31212$, $p < .05$; $F_2(1,13) = 3.61$, $MS_e = 3782$, $p < .1$).

413 ms; $F_1(1,61) = 3.82$, $MS_e = 27303$, $p < .1$; $F_2(1,15) = 5.27$, $MS_e = 4321$, $p < .05$).[8] No other effects on this region approached significance (Fs < 2).

Earlier in the sentence. As in first-pass times, more total time was spent on the main verb in ambiguous sentences than in unambiguous ones (387 vs 351 ms; $F_1(1,61) = 27.97$, $MS_e = 103261$, $p < .01$; $F_2(2,94) = 18.20$, $MS_e = 3773$, $p < .01$). There were no other effects at the main verb (all Fs < 1, except that the effect of verb type was marginal by participants: $F_1(2,122) = 2.93$, $MS_e = 11806$, $p < .1$; $F_2 < 1$), nor did the total time spent on *that* differ significantly across verb types (SC-bias, 256 ms; EQ-bias, 265 ms; DO-bias, 285 ms; Fs < 2).

Correlations

Trueswell et al. (1993) found that verbs' *that*-preferences influenced how much difficulty readers had at both the temporarily ambiguous NP and at the disambiguation in temporarily ambiguous sentences: The more often *that* had been omitted from sentences containing a particular SC-bias verb in their norming study, the more quickly people read both the NP and the disambiguation following that verb in a *that*-less sentence. This was taken as evidence that reading times were longer on the NP following SC-bias verbs than following DO-bias verbs because readers expected a *that* but did not get it, rather than because revisions were triggered by newly arrived verb bias information. Juliano and Tanenhaus (1993) suggested that the familiarity of the verb, which was negatively correlated with its *that*-preference, was probably the factor responsible for the effect.

Correlations will be reported here for first-pass times only, since the goal was specifically to evaluate whether verb properties affected initial interpretation. Correlations between properties of verbs and sizes of ambiguity effects (differences in reading time between ambiguous and unambiguous versions of an item) were calculated for both the temporarily ambiguous NP and the disambiguation. Several verb properties were evaluated, including frequency of occurrence (Francis & Kucera, 1982), strength of SC- and DO-bias, and *that*-preference (i.e., the proportion of SC-completions that included a *that* in the norming study.) Frequencies of occurrence were log transformed and verb bias proportions arcsine transformed in all analyses. Correlations were calculated both across all conditions and within verb categories and plausibility levels. To make the most direct possible comparison to Trueswell et al., correlations were also calculated for the subset of the 10 most strongly biased SC-bias verbs, since the set of all 16 SC-biased verbs was not quite as strongly biased as those used by Trueswell et al.

In addition to simple regression analyses evaluating the effect of each verb property separately, hierarchical multiple regressions were calculated to evaluate *that*-preference effects once other verb properties were partialed out (Cohen & Cohen, 1983). This was important because, as noted previously by Juliano and Tanenhaus (1993), some of the verb properties were intercorrelated, sometimes quite strongly (see Table 5).

Predictor variables were constrained to enter the multiple regression in the following order: frequency of occurrence, SC-bias strength, DO-bias strength, and *that*-preference. This order was chosen to evaluate whether *that*-preference made an independent contribution beyond any effects it shared with other verb properties. Both SC-bias and DO-bias were included because, although they were generally strongly negatively correlated with each other (see Table 5), their intercorrelation was not perfect, so it seemed worthwhile to evaluate whether they made independent contributions. To address the question of whether their effects completely overlapped, additional hierarchical analyses were done reversing their entry order. In the following paragraphs, values of simple correlations are given, followed by the percentage of variance

[8] The ambiguity effect after EQ-bias verbs was only marginal in the analysis with the two miscoded verbs reclassified ($F_1(1,61) = 3.09$, $MS_e = 29069$, $p < .1$; $F_2(1,13) = 3.35$, $MS_e = 4753$, $p < .1$).

TABLE 5

INTERCORRELATIONS AMONG VERB PROPERTIES

	All verbs			SC-bias verbs			DO-bias verbs			EQ-bias verbs		
	V freq[a]	SC-bias	DO-bias	V freq	SC-bias	DO-bias	V freq	SC-bias	DO-bias	V freq	SC-bias	DO-bias
SC-bias	−.02			−.05			−.26			.03		
DO-bias	−.01	−.61		−.03	.39		.30	−.61		−.10	.61	
that-pref	−.18	−.65	.61	−.31	.02	−.05	.15	−.80	.52	−.75	−.32	−.08

[a] V freq, verb's log transformed frequency of occurrence (Francis & Kucera, 1982).

independently accounted for by a variable after partialing out effects of other variables preceding it in the hierarchical multiple regression.

That-preference and verb frequency. In contrast with Trueswell et al.'s findings, degree of difficulty at the NP and the disambiguation were not significantly correlated with *that*-preference across either the 10 strongest SC-bias items or all 16 SC-bias items (rs $< -.25$, Fs < 2). (Kennison [submitted] and Schmauder and Egan [submitted] have both also failed to replicate *that*-preference effects in sentences with SC-bias verbs.) When all items were considered together, a small simple correlation between *that*-preference and difficulty at the disambiguation reached significance ($r = .23$, $F(1,94) = 5.15$, $p < .05$), but did not remain so when other verb properties were partialed out (0% variance independently accounted for, $F < 1$). *That*-preference effects dropped to near zero as soon as either of the two verb bias measures entered, so *that*-preference appeared to make no independent contribution beyond effects shared with verb bias.

In contrast with Juliano and Tanenhaus's findings, difficulty at the NP and disambiguation were also not significantly correlated with verb frequency, either across all items or within just the 10 strongest SC-bias items (rs $< .25$, Fs < 2).[9] Thus, neither *that*-preference nor verb familiarity reliably influenced how much difficulty readers had in ambiguous sentences.

Verb bias. The factor that most consistently influenced amount of difficulty at the disambiguation was the strength of a verb's bias, which had small but reliable overall effects (see Fig. 3). Across all items, the two types of verb bias had effects of comparable size but in opposite directions: Difficulty decreased as a verb's SC-bias increased ($r = -.27$, $F(1,94) = 7.36$, $p < .01$), and conversely, difficulty increased as DO-bias increased ($r = .27$, $F(1,94) = 7.22$, $p < .01$). The influence of the two types of bias overlapped substantially, since whichever one entered the hierarchical multiple regression first claimed the effect, leaving no independent contribution from the other.

An examination of correlations separately for the plausible and implausible conditions within each of the verb subtypes was particularly informative: The influence of verb bias on amount of difficulty at the disambiguation was significant only when plausibility supported the verb's less frequent structural alternative, i.e., when the two cues provided conflicting information. When *SC-bias verbs* were followed by NPs that were *plausible* as direct objects, difficulty increased significantly as the verb's DO-bias increased ($r = .53$, 36% of variance independently accounted for, $F(1,12) = 8.26$, $p < .05$). Thus, although the factorial analysis showed that readers had no significant difficulty overall

[9] Juliano and Tanenhaus reported correlations between verb frequency of occurrence and reading time on the determiner *the* in ambiguous sentences (1993) or with the difference between the determiner *the* in ambiguous sentences and the complementizer *that* in unambiguous sentences (1994), in both cases for sentences with SC-bias verbs only. It was not possible to calculate these correlations in our eyetracking study because the determiner was skipped too often to allow it.

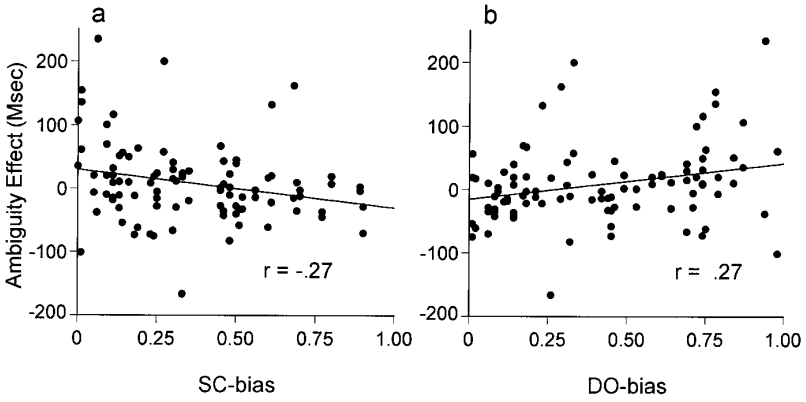

FIG. 3. SC-bias (a) and DO-bias (b) strengths plotted against the ambiguity effect at the disambiguating region in first-pass reading times in Experiment 1 across all items.

at the disambiguation in sentences with SC-bias verbs regardless of plausibility, correlations showed that when the NP following such a verb was plausible as a direct object, difficulty increased as the verb's likelihood of taking direct objects increased. When SC-bias verbs were followed by a NP that was implausible as a direct object, the influence of DO-bias was smaller and not significant ($r = .25$, 8% of variance independently accounted for, $F = 1$).

In parallel but opposite fashion, SC-bias significantly influenced difficulty at the disambiguation in sentences with *DO-bias verbs* only where the NP following the verb was *implausible* as a direct object, i.e., again when plausibility supported the verb's less frequent structural alternative (simple $r = -.58$, 29% of variance independently accounted for, $F(1,13) = 5.75$, $p < .05$). So, for DO-bias verbs, while the factorial analysis showed that readers generally had difficulty at the disambiguation, correlations showed that when the NP was implausible as a direct object, the degree of difficulty decreased as the verb's likelihood of taking sentential complements increased. When DO-bias verbs were followed by NPs that were plausible as direct objects, the influence of SC-bias was smaller and not significant ($r = -.26$, 6% of variance independently accounted for, $F < 2$). So, for both SC- and DO-bias verbs, verb bias had graded effects on the difficulty at the disambiguation, which were significant only when plausibility supported the verb's less frequent structural alternative.

Finally, there were no significant correlations between verb bias and reading times on the temporarily ambiguous NP (rs $< .1$, Fs < 1).

Discussion

The results of Experiment 1 generally replicated the verb bias effects found by Trueswell et al., and in so doing ruled out the concern that their results were obtained only because verb bias and plausibility were conflated in their materials. Sentences containing SC-bias verbs caused no significant difficulty for readers at the disambiguation, while sentences with DO-bias verbs did, and neither pattern interacted significantly with plausibility. In contrast, plausibility did significantly affect reading times at the disambiguation in sentences with EQ-bias verbs: When a plausible NP followed an EQ-bias verb, readers had difficulty at the disambiguation, but not when the NP was implausible. The pattern of plausibility effects across verb type showed that the two factors interacted, and the particular pattern of interaction was the predicted one: Plausibility had the most impact when verbs were not biased. This pattern is predicted by constraint-based comprehension models, but

could also be accounted for by other kinds of models. In particular, two-stage models could explain the results if the interaction were the result of revision.

There was evidence in first-pass times on the temporarily ambiguous NP, however, suggesting that verb bias guided interpretation of the NP from the start. In sentences with DO-bias verbs, first-pass times on an implausible ambiguous NP were slower than for both the same NP in an unambiguous sentence and a plausible NP in an ambiguous sentence, suggesting that the NP was interpreted as a direct object after those verbs. In contrast, there was no effect of plausibility on the NP in sentences with SC-bias verbs, suggesting that the direct object interpretation was never seriously considered in those cases. This pattern is most consistent with a processing system in which verb bias guides initial interpretations rather than one in which it aids revision.

Plausibility effects were expected and found at the disambiguation in sentences with EQ-bias verbs, but part of the interaction with plausibility came from an unexpected ''reverse ambiguity effect'' in sentences with implausible NPs, i.e., significantly faster first-pass times in ambiguous sentences than in unambiguous ones. An examination of the reading times in Table 3 shows that the effect was primarily due to fast times in the implausible ambiguous condition. Several features of the eye movement patterns were examined in search of an explanation.

One possibility was that readers regressed back to earlier parts of the sentence as soon as they reached the disambiguation in ambiguous sentences with EQ-bias verbs and implausible NPs, which would result in short first-pass times on the disambiguating region. Frequency of regressions sometimes reveals comprehension difficulty when first-pass times do not (e.g., Altmann et al., 1992; Schmauder and Egan, submitted). However, the probability of ending the first pass on the disambiguation with a regression did not differ between the ambiguous and unambiguous conditions with EQ-bias verbs and implausible NPs (9% vs 6%, Fs < 2). Furthermore, when first-pass times were calculated using only those trials without such regressions, the pattern of results did not change. Readers also did not spend more time anywhere earlier in the sentence before reaching the disambiguation in ambiguous sentences with EQ-bias verbs followed by implausible NPs.

Another possibility was that readers happened to get more parafoveal preview of the first disambiguating word in ambiguous sentences with EQ-bias verbs and implausible NPs, allowing them to move through the disambiguating region quickly. The first disambiguating word was always a short, high-frequency auxiliary verb, which would be particularly likely to be identifiable from preview (Inhoff & Rayner, 1986; McConkie & Rayner, 1975). To examine this possibility, the incidence of fixations within 5 character positions to the left of the auxiliary verb was examined, on the assumption that such fixations were most likely to lead to identification of the auxiliary through preview. Readers did fixate within this window more often in the EQ-bias implausible ambiguous condition than in its unambiguous counterpart (57% vs 49%), but this does not seem to explain the first-pass reading time pattern, since the same pattern was present when trials where preview was likely were excluded.

In sum, an examination of eye movement patterns has revealed no explanation for the ''reverse ambiguity effect'' in the EQ-bias implausible conditions. Whatever the source of this half of the interaction between plausibility and ambiguity in sentences with EQ-bias verbs, though, the fact remains that it was only for these verbs that there was a reliable interaction: Ambiguous sentences with EQ-bias verbs were difficult when the NP was plausible as a direct object, and not when it was implausible. Thus, the prediction that plausibility effects would emerge most strongly when verbs were unbiased was largely confirmed. However, the ''reverse ambiguity effect'' for EQ-bias verbs remains troublesome, and the fact that comprehension accuracy was also slightly higher for items with EQ-bias verbs suggests that they may have differed in

some unknown way from the other sentences. To further evaluate this possibility, a self-paced moving window study was conducted using the same materials to determine whether the results would replicate with another measure.

Finally, multiple regression revealed that there were graded effects of verb bias that depended on plausibility. Specifically, the relative strengths of the two types of bias affected the degree of difficulty at the disambiguation significantly only when plausibility supported the verb's less likely alternative. In contrast with Trueswell et al., no correlation was found between *that*-preference and difficulty at either the temporarily ambiguous NP or the disambiguation for SC-bias verbs. Further discussion of the patterns of correlation will be postponed until after the second experiment.

EXPERIMENT 2

A self-paced moving window study was conducted using the same materials as Experiment 1. In addition to providing additional evidence about the sentences with EQ-bias verbs, this study provides a direct comparison between the two most widely used sentence comprehension paradigms.

Method

Participants

Eighty-two University of Illinois students (41 females, 41 males; mean age 21) participated for either partial course credit or payment. All participants were native English speakers. Two participants were excluded from all analyses due to poor performance on the comprehension questions (error rate greater than 15%).

Materials and Design

The stimuli and design were identical to Experiment 1. The one difference was that item order was randomized separately for each participant.

Procedure

Participants were seated in front of an IBM-compatible computer on which stimulus presentation and response collection were controlled by the MicroExperimental Laboratory (MEL) software package. Sentences were presented in noncumulative word-by-word self-paced moving window fashion. At the start of each trial, dashes appeared on the screen replacing each nonspace character in the sentence. Participants pressed the spacebar on the keyboard with their dominant hand to change each successive group of dashes into a word, and the timing of the spacebar presses was recorded. With each spacebar press, the current word reverted to dashes as the next word was converted to letters. All of the experimental sentences fit onto a single line, while some fillers extended over two lines. Yes/no comprehension questions were presented after each sentence and participants pressed one of two keys on the keyboard to answer them, after which they received feedback. Each participant saw 10 practice items, followed by one of the four lists. The experiment lasted approximately 25 min.

Results

The overall error rate on comprehension questions was 5%, and as in Experiment 1, there was a small effect of verb bias on accuracy by participants ($F_1(2,158) = 3.16$, $MS_e = 105$, $p = .05$; $F_2(2,45) < 1$). In contrast to Experiment 1, though, where slightly fewer questions were missed after sentences with EQ-bias verbs, here slightly more questions were missed after those sentences (6%) than after sentences with other verb types (SC-bias, 4%; DO-bias, 5%). There were no effects of ambiguity (5% vs 5%) or plausibility (5% vs 4%) on accuracy (all Fs < 1). Trials with incorrectly answered comprehension questions were excluded from reading time analyses.

Reading Times

Reading times were adjusted for length differences in the manner described for Experiment 1, except that words rather than regions were the units over which the regression equations were calculated, and the resulting residual times were submitted to analyses of vari-

TABLE 6

EXPERIMENT 2 READING TIMES

Sentence region	Plausible			Implausible		
	Ambiguous	Unambiguous	Ambiguity effect	Ambiguous	Unambiguous	Ambiguity effect
DO-bias items						
Main V (. . . *wrote*)	399 (17)	385 (1)	14 (16)	381 (−2)	379 (−6)	2 (4)
Complementizer (*that*)	—	379 (33)	—	—	366 (20)	—
Ambig NP (*the interview/painting*)	365 (14)	335 (−17)	30 (31)	359 (11)	339 (−10)	20 (21)
Disambiguation (*had been*)	364 (17)	343 (−5)	21 (22)	357 (9)	340 (−10)	17 (19)
Post-disambiguation	341 (−4)	336 (−10)	5 (6)	340 (−9)	348 (−3)	−8 (6)
EQ-bias items						
Main V (. . . *regretted*)	387 (7)	370 (−5)	17 (12)	376 (−4)	385 (6)	−9 (−10)
Complementizer (*that*)	—	358 (14)	—	—	365 (19)	—
Ambig NP (*the decision/reporter*)	366 (13)	334 (−16)	32 (29)	348 (−3)	334 (−18)	14 (15)
Disambiguation (*had ever*)	352 (4)	335 (−10)	17 (14)	345 (−2)	344 (−4)	1 (2)
Post-disambiguation	337 (−10)	333 (−10)	4 (0)	332 (−18)	338 (−10)	−6 (−8)
SC-bias items						
Main V (. . . *confessed*)	369 (−9)	368 (−12)	1 (−3)	381 (3)	378 (−3)	3 (6)
Complementizer (*that*)	—	361 (14)	—	—	351 (4)	—
Ambig NP (*the robbery/vault*)	349 (−4)	333 (−21)	16 (17)	354 (3)	336 (−16)	18 (19)
Disambiguation (*had been . . .*)	337 (−11)	338 (−12)	−1 (1)	347 (−1)	340 (−10)	7 (9)
Post-disambiguation	334 (−14)	340 (−9)	−6 (−5)	339 (−7)	339 (−7)	0 (0)

Note. Numbers in parentheses are residuals after length correction. See text.

ance. Within each sentence position, reading times beyond 2.5 *SD* above or below a participant's mean were replaced with a cutoff value equal to the 2.5 *SD* value, affecting 3% of the data. Analyses were conducted on the same sentence regions as in Experiment 1, with reading times for multiple word regions obtained by averaging across the words in the region. Mean uncorrected reading times (trimmed at 2.5 *SD* with replacement) and length-corrected residuals are presented in Table 6, and ambiguity effects at the two critical regions are shown in Fig. 4.

The disambiguation (Fig. 4a). For sentences with DO-bias verbs, the disambiguating region was read significantly more slowly in ambiguous sentences than in unambiguous ones (361 vs 342 ms; $F_1(1,79) = 13.34$, $MS_e = 2349$, $p < .01$; $F_2(1,15) = 20.84$, $MS_e = 318$, $p < .01$), and a smaller overall ambiguity effect approached significance by participants in sentences with EQ-bias verbs (349 vs 340 ms; $F_1(1,79) = 3.21$, $MS_e = 1643$, $p < .1$; $F_2(1,15) = 2.80$, $MS_e = 362$, $p > .1$), but there was no difference in sentences with SC-bias verbs (342 vs 339 ms; Fs < 2). There was no main effect of plausibility at the disambiguation for any of the verb types (SC-bias items, 338 vs 344, Fs < 2; EQ-bias items, 344 vs 345, Fs < 2; DO-bias items, 354 vs 349 ms; $F_1(1,79) = 2.08$, $MS_e = 1665$, $p > .1$, $F_2 < 2$).

In sentences with DO-bias verbs, reading times were slower in ambiguous sentences than in unambiguous ones both when the NP was plausible as a direct object (364 vs 343 ms; $F_1(1,79) = 7.38$, $MS_e = 2757$, $p < .01$; $F_2(1,15) = 12.01$, $MS_e = 332$, $p < .01$) and when it was implausible (357 vs 340 ms; $F_1(1,79) = 7.62$, $MS_e = 1521$, $p < .01$; $F_2(1,15) = 6.08$, $MS_e = 443$, $p < .05$), and there was no interaction between the two factors (Fs < 1). In sentences with SC-bias verbs, there were no significant differences in reading times between ambiguous and unambiguous sentences, again regardless of the plausibility of the NP as a direct object (plausible, 337 vs 338 ms; implausible, 347 vs 340 ms; Fs $\leqslant 2$), and no interaction (Fs < 1). In sentences with EQ-bias verbs, however, reading times at the disambiguation were longer in ambiguous sentences than in unambiguous ones when the NP was plausible as a direct object (352 vs 335 ms; $F_1(1,79) = 4.18$, MS_e

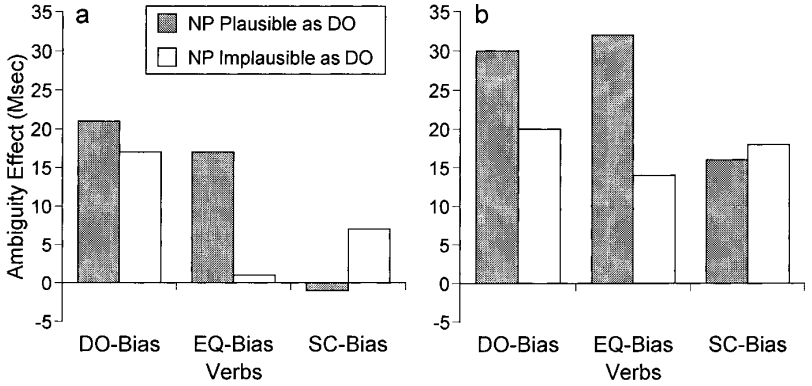

FIG. 4. Ambiguity effects (ambiguous minus unambiguous) at the disambiguating region (a) and at the temporarily ambiguous NP (b) in self-paced moving window reading times in Experiment 2.

= 2206, $p < .05$; $F_2(1,15) = 4.08$, MS_e = 365, $p < .1$), but they did not differ when it was implausible (345 vs 344 ms; Fs < 1).[10] Although this difference was not enough to produce a significant interaction between plausibility and ambiguity (Fs < 2), there was thus some evidence that plausibility had stronger effects for EQ-bias verbs than for the other verbs.

The temporarily ambiguous NP (Fig. 4b). The NP was read more slowly in ambiguous than in unambiguous sentences with all three types of verbs (SC-bias, 352 vs 335 ms; $F_1(1,79) = 8.57$, $MS_e = 3025$, $p < .01$; $F_2(1,15) = 36.83$, $MS_e = 151$, $p < .01$; DO-bias, 362 vs 337 ms; $F_1(1,79) = 24.25$, MS_e = 2349, $p < .01$; $F_2(1,15) = 21.75$, MS_e = 507, $p < .01$; EQ-bias, 357 vs 334 ms; $F_1(1,79) = 17.91$, $MS_e = 2047$, $p < .01$; $F_2(1,15) = 8.48$, $MS_e = 889$, $p = .01$). Plausibility significantly affected reading times on the NP only in sentences with EQ-bias verbs (350 vs 341 ms; $F_1(1,61) = 5.29$, $MS_e = 1471$, $p < .05$; $F_2(1,15) = 4.63$, $MS_e = 244$, $p <$ .05; Fs for other verbs $\leqq 1$), and for those items the interaction between plausibility and ambiguity also approached significance by items ($F_1(1,79) = 2.24$, $MS_e = 2277$, $p > .1$; $F_2(1,15) = 3.11$, $MS_e = 253$, $p < .1$),[11] because the ambiguity effect was larger for items with plausible NPs (366 vs 334 ms; $F_1(1,61)$ = 11.82, $MS_e = 2923$, $p < .01$; $F_2(1,15)$ = 12.45, $MS_e = 530$, $p < .01$) than for items with implausible NPs (348 vs 334 ms; $F_1(1,61)$ = 5.14, $MS_e = 1401$, $p < .05$; $F_2(1,15) = 2.82$, $MS_e = 612$, $p > .1$). A similar pattern in sentences with DO-bias verbs did not approach significance (plausible, 365 vs 335 ms; implausible, 359 vs 339 ms; Fs < 2), and there was no evidence of any effect of plausibility in sentences with SC-bias verbs.

Earlier in the sentence. At the main verb, there were no significant differences among conditions (all Fs < 2 except that the verb bias by plausibility interaction approached significance: $F_1(2,158) = 2.60$, $p < .1$; $F_2(2,94) = 2.60$, $p < .1$. Note that the plausible and implausible versions of sentences were still identical at the verb.) Reading times on *that* differed depending on which type of verb it followed, reliable only by participants ($F_1(2,158) = 3.43$, $p < .05$; $F_2 < 2$). *That*-times were significantly longer after DO-bias verbs than after SC-bias verbs (373 vs 356 ms; $F_1(1,79) = 6.53$, $p < .05$; $F_2(1,47) = 3.86$,

[10] In the analysis where the two miscoded EQ-bias verbs were recoded, the ambiguity effect in sentences with plausible NPs was only marginal by participants ($F_1(1,79) = 2.84$, $MS_e = 2838$, $p < .1$; $F_2(1,13) = 2.45$, $MS_e = 325$, $p > .1$).

[11] In the analysis where the two miscoded EQ-bias verbs were recoded, the plausibility by ambiguity interaction no longer approached significance by items (Fs < 2).

$p < .1$), but times after EQ-bias verbs (362 ms) did not differ significantly from either of the others (Fs $\leqq 2$).

Correlations

Correlational analyses were again conducted using differences between ambiguous and unambiguous conditions as the measure of the difficulty caused by the temporary ambiguity, with similar results as in Experiment 1.

That-preference and verb frequency. As in Experiment 1, *that*-preference did not reliably influence the size of the ambiguity effect at either the NP or the disambiguation across sentences with the 10 strongest SC-bias verbs or all 16 SC-bias verbs (rs $< -.25$, Fs < 2). Also as in Experiment 1, a small correlation across all items reached significance at the disambiguating region ($r = .28$, $F(1,94) = 7.70$, $p < .01$), but dropped to near zero again as soon as either of the verb bias measures entered the hierarchical multiple regression (1% of variance independently accounted for, $F < 1$). Thus, as in Experiment 1, *that*-preference made no independent contribution beyond its shared effects with verb bias. Also as in Experiment 1, verb frequency had no significant effect on difficulty at either the NP or the disambiguation (rs $< .20$, Fs < 2).[12]

[12] Because there were reading times for every word in the moving window study, unlike the eyetracking study, it was possible to calculate correlations between verbs' frequency of occurrence and reading times on the determiner *the* following the verb in ambiguous sentences with SC-bias verbs, for comparison to Juliano and Tanenhaus (1993). Consistent with their findings, there was a negative correlation (all 16 SC-bias items: $r = -.31$, 10 strongest SC-bias verbs: $r = -.45$), though it was not reliable (Fs < 2). Their explanation for this correlation was that readers expected to see the word *that* after SC-bias verbs because most sentential complements begin with *that*, but when the next word turned out to be *the*, they had less difficulty with the violation of expectation for more familiar verbs. However, our results suggested that such correlations with verb frequency were due to simple frequency spillover effects, i.e., that any word following the verb was read faster as the verb's frequency increased. Similar effects were observed in sentences with the other types of verbs (DO-bias items, $r = -.33$; EQ-bias items, $r = -.35$; Fs < 2), leading to a reliable effect across all items together ($r = -.32$, $F(1,46) = 5.27$, $p < .05$), and there was an even stronger correlation with reading times on *that* in unambiguous sentences (across all items, $r = -.51$, $F(1,46) = 16.29$, $p < .01$; 16 SC-bias items, $r = -.31$; 10 strongest SC-bias items, $r = -.29$, Fs < 2). Thus, the effect seemed not to be due to specific expectations about what word should follow a particular type of verb.

Verb bias. There were no significant correlations between verb bias and reading times at the temporarily ambiguous NP (rs $< .10$, Fs < 2). Verb bias did, however, influence difficulty at the disambiguation, again as in Experiment 1 (see Fig. 5). Across all items, the two types of verb bias each had small but reliable effects on the amount of difficulty readers had at the disambiguation, once again in opposite directions: Difficulty decreased as SC-bias increased ($r = -.38$, $F(1,94) = 15.44$, $p < .01$), and conversely, difficulty increased as DO-bias increased ($r = .26$, $F(1,94) = 6.56$, $p = .01$).

Examining correlations between verb bias and degree of difficulty at the disambiguation separately for the verb subsets and the plausible and implausible conditions also revealed a pattern similar to that in Experiment 1: Verb bias significantly influenced degree of difficulty at the disambiguation only when plausibility supported a verb's less frequent structural alternative. There was one difference from the pattern observed in Experiment 1, however, in that here, both types of bias made significant contributions, while in Experiment 1 only the strength of a verb's less likely alternative contributed significantly. So here, when *SC-bias verbs* were followed by NPs that were *plausible* as direct objects, both SC-bias and DO-bias were correlated with the size of the ambiguity effect at the disambiguation (SC-bias, $r = -.57$, 33% of variance independently accounted for, $F(1,13) = 6.32$, $p < .05$; DO-bias, $r = .47$, 57% of variance independently accounted for, $F(1,12) = 63.66$, $p < .01$). When SC-bias verbs were followed by a NP that was implausible as a direct object, verb bias's influence was again smaller and not significant (SC-bias, $r = -.34$, 10% of variance independently accounted for, $F < 2$; DO-bias, $r = -.17$, 0% of variance independently accounted for, $F < 1$).

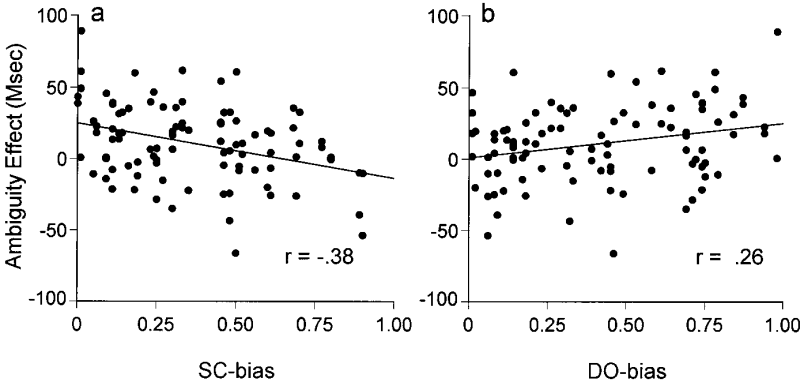

FIG. 5. SC-bias (a) and DO-bias (b) strengths plotted against the ambiguity effect at the disambiguating region in reading times in Experiment 2 across all items.

For *DO-bias verbs,* bias correlated significantly with degree of difficulty at the disambiguation only where the NP following the verb was *implausible* as a direct object, again as in Experiment 1. Both types of bias significantly influenced degree of difficulty at the disambiguation (SC-bias, $r = -.59$, 34% of variance independently accounted for, $F(1,13) = 6.80$, $p < .05$; DO-bias, $r = .71$, 21% of variance independently accounted for, $F(1,12) = 5.87$, $p < .05$). When DO-bias verbs were followed by NPs that were plausible as direct objects, verb bias effects were again smaller and not significant (SC-bias, $r = -.14$, 0% of variance independently accounted for, $F < 1$; DO-bias, $r = -.32$, 22% of variance independently accounted for, $F(1,12) = 4.74$, $p < .1$). Thus, for both SC- and DO-bias verbs, verb bias once again had graded effects on the difficulty at the disambiguation, especially when plausibility supported the verb's less frequent structural alternative.

Discussion

The results at the disambiguating region replicated Experiment 1, with one important exception. Readers again had significant difficulty at the disambiguation only when the verb was one that most often takes direct objects, and this was true regardless of the plausibility of the temporarily ambiguous NP as a direct object for the verb. Readers did not have significant difficulty at the disambiguation when the verb was one that most often takes sentential complements, again regardless of the plausibility of the noun as a direct object. When the verb was one that is used equally often with direct objects and sentential complements, readers had difficulty at the disambiguation only when the plausibility of the noun supported a direct object interpretation. Thus, once again, when verb bias was strong, plausibility had little effect, but when verbs were not biased, plausibility played a significant role.

The important exception is that the odd ''reverse ambiguity effect'' in sentences with implausible NPs and EQ-bias verbs did not replicate. The stimuli were identical, so the difference between experiments is likely due to some as yet undiscovered aspect of the eye movement patterns or to unknown differences in the groups of participants in the studies. Otherwise, the overall pattern in sentences with EQ-bias verbs was quite similar across the two experiments; i.e., plausibility affected difficulty at the disambiguation.

The results at the temporarily ambiguous NP replicated Experiment 1 in one respect but not others. The consistent finding was that plausibility had no effect on reading times on the NP after SC-bias verbs, suggesting that readers did not seriously consider a direct object interpretation of the NP in those senten-

ces. In most other respects, results at the NP were rather different across the two experiments. In the first experiment, plausibility affected reading times on the NP significantly after DO-bias verbs but not EQ-bias verbs, but it was the other way around in the second experiment. Most surprising was the direction of plausibility effects in the second experiment: Reading times were longer on plausible NPs than on implausible NPs, reversing the more expected pattern seen in Experiment 1, where times were faster on plausible NPs.

One possible explanation for the discrepancy across the experiments at the NP is that the relatively high proportion of sentences containing sentential complements (44%), together with the slower reading times forced by the self-paced reading paradigm, led readers to develop an expectation for sentential complements, causing them to slow down whenever verb bias and plausibility together went against that expectation. The fact that there were robust ambiguity effects at the disambiguation in sentences with DO-bias verbs argues against the development of a completely general expectation for sentential complements, but it is still possible that such expectations played some role. Notice, though, that such an account requires readers to have rapid access to both verb bias and plausibility information and the ability to put them together quickly enough to affect reading times on the noun.

In addition to the verb bias effects observed at the NP and disambiguation, reading times for the complementizer *that* suggested that verb bias was available rapidly enough to affect reading times on the immediately following word: *That* was read significantly faster after SC-bias verbs than after DO-bias verbs, suggesting that readers expected to see *that* after the SC-bias verbs. There was a similar but nonsignificant pattern in Experiment 1, and a meta-analysis combining reading times on *that* from the two experiments will be presented in the general discussion.

Finally, multiple regression analyses revealed that there were graded effects of bias that depended on plausibility, as there were in Experiment 1. Specifically, the relative strengths of both kinds of bias affected the degree of difficulty at the disambiguation more strongly when plausibility supported the less frequent alternative. This result will be discussed further in the next section.

GENERAL DISCUSSION

The picture that emerges from the studies presented here is that readers' prior experience with particular verbs guided their interpretation of a temporary ambiguity following those verbs. Several features of the results suggest that verb bias guided initial interpretation. First, there were no effects at the NP in either experiment of the plausibility of the temporarily ambiguous NP as a direct object in sentences with SC-bias verbs. Care was taken to equate the plausibility manipulation for all three kinds of verbs, so the absence of plausibility effects in sentences with SC-bias verbs, together with their presence in sentences with other verbs, suggests that verb bias guided readers away from a direct object interpretation of the NPs in sentences with SC-bias verbs.

One qualification to the claim that plausibility had no effect in sentences with SC-bias verbs was that verb bias strength correlated significantly with difficulty at the disambiguation only when plausibility supported a direct object interpretation. This result suggests that the direct object interpretation received more weight as the likelihood of using a particular SC-bias verb with direct objects increased, as long as the NP supported such an interpretation, implying that the two cues interacted to determine the extent to which a direct object interpretation was considered. Such an interactive pattern at the disambiguation could, however, be amenable to a filtering explanation: If verb bias became available and triggered revision while readers were still on the NP, plausibility could have come into play by the time readers reached the disambiguation and influenced revision at that point. However, it would seem that plausibility should have had some effect on reading times at the NP in sentences with SC-bias verbs on such

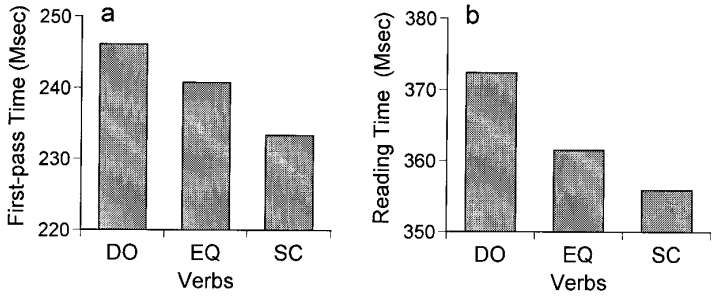

FIG. 6. Reading times on the complementizer *that* across both experiments. (a) Experiment 1, eyetracking first pass times; (b) Experiment 2, moving window reading times.

an account, since the NP should have been analyzed as a direct object at least briefly. There was no hint of any such effect in either experiment.

Contrary to Trueswell et al.'s results (1993; see also Juliano & Tanenhaus, 1993, 1994), and consistent with Kennison's (submitted) and Schmauder and Egan's (submitted) results, in our studies neither *that*-preference nor verb frequency correlated significantly with the size of the ambiguity effect in sentences with SC-bias verbs. Thus, we did not replicate the aspect of Trueswell et al.'s (1993) results that showed the earliest effects of a lexical factor and provided the strongest support for lexical guidance over lexical filtering. However, other evidence that verb bias began to influence interpretation very rapidly in our studies came from two sources. One is the above-mentioned absence of any plausibility effects at the NP in sentences with SC-bias verbs, and the other is the pattern of reading times on the complementizer *that*, shown in Fig. 6 for both studies.

That was read fastest after SC-bias verbs and slowest after DO-bias verbs in both studies. The difference was significant only in the moving window study, but this may be attributable to the fact that *that* was skipped 44% of the time in the eyetracking study. To evaluate whether reading times on *that* were affected by verb bias in the same way across both experiments, a meta-analysis was conducted with experiment as a between-participants but within-items factor. Times were overall faster in the eyetracking study, leading to a main effect of experiment ($F_1(1,136) = 11.72$, $MS_e = 3364$, $p < .01$; $F_2(1,45) = 20.05$, $MS_e = 544$, $p < .01$), but most importantly, *that* reading times differed significantly across verbs by both participants and items ($F_1(2,272) = 4.33$, $MS_e = 1593$, $p < .05$; $F_2(2,45) = 3.18$, $MS_e = 580$, $p < .05$), and there was no interaction between the verb effect and experiment (Fs < 1). Thus, reading times on the complementizer differed depending on which verb it followed, consistently across the two experiments. Contrasts on the pooled results revealed that reading times on *that* were significantly faster after DO-bias verbs than after SC-bias verbs ($F_1(1,136) = 8.98$, $MS_e = 1532$, $p < .01$; $F_2(1,45) = 6.36$, $MS_e = 580$, $p < .05$), but neither differed significantly from times after EQ-bias verbs (Fs < 2, except for the participant-based contrast comparing SC-bias and EQ-bias verbs: $F_1(1,136) = 2.48$, $MS_e = 1622$, $p > .1$). Readers thus read the word *that* more quickly after verbs that are usually followed by sentential complements.

A reason to be cautious, however, about attributing differences in *that* reading times to verb bias is that DO-bias verbs were slightly longer on average (8.3 letters) than either SC-bias (7.7 letters) or EQ-bias verbs (7.6 letters). Perhaps readers were slower on *that* after DO-bias verbs because of spillover effects from having just read a longer word. (The length correction procedure removed effects of a word's own length, but not spillover effects due to the length of the preceding word.) To evaluate this possibility, a hierarchical multiple regression was calculated between verb

properties and *that* reading times pooled across the two experiments. Across all items, *that* was indeed read more slowly as verb length increased ($r = .27$, $F(1,94) = 7.28$, $p < .01$), so the difference in *that*-reading times following SC- and DO-bias verbs was apparently partly due to spillover from length differences between the verbs. Reading times on *that* also increased as verb frequency decreased ($r = -.29$, $F(1,94) = 7.28$, $p < .01$), which could either be specific to *that* following verbs that can take sentential complements or a general frequency spillover effect. Most importantly, there were small but reliable effects of verb bias on *that* reading times after length and frequency effects were partialed out (SC-bias, $r = -.22$, 5% of variance independently accounted for, $F(1,92) = 5.99$, $p < .05$; DO-bias, $r = .20$, 4% of variance independently accounted for, $F(1,91) = 4.29$, $p < .05$). As usual, whichever of the two verb bias measures entered first claimed the effect. A similar correlation between *that* reading times and *that*-preference dropped to near zero as soon as one of the verb bias measures entered ($r = .21$, 0% of variance independently accounted for, $F < 1$). Thus, the differences in reading times on the word *that* after SC-bias and DO-bias verbs were partially attributable to verb bias, which shows verb bias was available rapidly enough to influence processing of the very next word. This result is not consistent with a filtering explanation of the role of verb bias.

In addition to its effects at the complementizer, verb bias also had graded effects on reading times at the disambiguation in both studies, such that difficulty at the disambiguation decreased as SC-bias increased and increased as DO-bias increased. The conditions that contributed most to these effects were those where plausibility supported a verb's less frequent alternative, i.e., where verb bias and plausibility conflicted. This pattern suggests that multiple interpretations of the ambiguity were pursued in parallel, each gaining or losing strength as additional constraints came into play. Such an effect could be explained in the following way: The structural possibilities allowed by a verb were retrieved, weighted according to their relative frequencies, in the process of recognizing the verb. Then the following NP added weight to each of the alternatives, according to its plausibility in each structure. When plausibility supported the same interpretation as verb bias, the relative weights of the alternatives diverged further, with the result that small differences between their weights mattered less. In contrast, when plausibility supported the verb's less likely alternative, it caused the weights of the two alternative interpretations to converge, making small differences between their weights more important. Thus, when plausibility supported a verb's less frequent structural alternative, differences in the relative weights of the alternatives played a stronger role in distinguishing them, leading to significant correlations between reading times and verb bias. Parallel constraint-based models in general would predict these results, with different models providing different mechanisms, such as discarding alternatives below a threshold, pruning low-weighted alternatives through beam search (Gibson, 1991; Jurafsky, 1996), or the effect of relative distances from competing attractors in an attraction space (Tabor et al., in press).[13]

The prediction that verb bias would dominate its interaction with plausibility was not derived from inherent properties of the architecture of constraint-based models, which do not in principle attempt to differentiate between different stages in comprehension, nor do they stipulate delays in the availability or use of any information relevant to interpretation. The prediction was based on two kinds

[13] The explanation given for graded verb bias effects at the disambiguation implies that such effects should also have been found for EQ-bias verbs, since the two alternative interpretations should start out nearly equally weighted for them. However, the criterion for choosing EQ-bias verbs may have worked against finding such correlations. They were chosen to have nearly equal SC- and DO-bias, so the two bias measures were strongly positively correlated for them ($r = .62$), unlike the tradeoff between the two types of bias that was present for the other verbs.

of observations. First, the claim that sentence comprehension relies on the same processes as lexical comprehension has been made in some constraint-based models, leading to the prediction that an interaction between a frequency-based bias and contextual plausibility observed for the resolution of lexical ambiguity would also occur for structural ambiguities. Second, properties of the two kinds of information suggest reasons for their asymmetric effects. As discussed earlier, verb bias might be expected to become available more rapidly than plausibility since it may be a retrievable property of a single word, while plausibility must be computed for particular word combinations. Another factor is the sheer amount of experience people have with the relevant kinds of information (Pearlmutter & MacDonald, 1995). Verb bias is built up across many sentences containing a particular verb, where the other words around it vary across those sentences. We thus have more experience with a verb occurring in some structure, abstracting away from the other words that are part of that structure, than we have with particular combinations of words. Finally, a consideration of the nature of the constraint supplied by frequency-based biases and plausibility suggests that verb bias might generally be more effective (MacDonald et al., 1994b; Spivey-Knowlton, Trueswell, & Tanenhaus, 1993; Trueswell, 1996; Trueswell & Tanenhaus, 1994). Verb bias provides a small set of structural possibilities allowed by the verb, weighted according to their relative frequencies. By itself, plausibility can rarely constrain the possibilities so narrowly in advance. Thus, plausibility is likely to be most effective when other factors have substantially constrained the possibilities and it provides a basis on which to choose among those possibilities.

One final point regarding the pattern of interaction observed here may be important. Much of the work on the role of lexical factors in the initial interpretation of structural ambiguity has emphasized the importance of verbs, partly because many of the structural ambiguities that arise in English concern the relationship between a verb and some phrase in the sentence (Ford, Bresnan, & Kaplan, 1982). Our results suggest that verb properties had a stronger influence than plausibility, seeming to confirm the dominance of verbs. However, its apparent dominance here might simply be due to the fact that the verb preceded the temporarily ambiguous NP in the sentences we investigated.

Two recent studies of a different kind of sentence provide some evidence relevant to this point (MacDonald, Pearlmutter, & Seidenberg, 1994a; Trueswell, 1996). In sentences like ''*The witness examined by the lawyer turned out to be unreliable,*'' there is a temporary ambiguity about whether the first verb (*examined*) is the main verb of the sentence, or instead part of a relative clause intervening between the subject noun and the main verb. In these sentences, the plausibility of a particular noun/verb combination can be informative about how to resolve the ambiguity (e.g., *The witness examined . . .* vs *The evidence examined . . .*), and the relevant NP precedes the verb in these sentences. Several studies have examined the effect of the plausibility of the subject NP as an agent of the verb in such sentences (e.g., Ferreira & Clifton, 1986; Pearlmutter & MacDonald, 1992; Rayner et al., 1983; Trueswell et al., 1994). MacDonald et al. (1994a) conducted a meta-analysis across several of these studies and discovered that whether or not plausibility effects were found in a given study depended on the relative frequencies of the past tense (the form in the main verb analysis) and past participle (the form in the relative clause analysis, since the relative clause is passive) forms of the verbs. More recently, Trueswell (1996) explicitly manipulated verb bias in this type of sentence and found the same pattern: Plausibility affected difficulty only when verbs were biased toward past participle usage. Thus, the effectiveness of plausibility as a cue depended on the relative frequencies of usage of the verb, much as it did in the studies reported here. The fact that a similar asymmetry in the relative contributions of verb bias and plausibility has been observed both when the verb precedes and when it follows the relevant NP suggests

that verb bias may indeed be the generally more effective constraint, perhaps because it is more rapidly accessible, and/or based on more experience, and/or more constraining. It is important to keep in mind, however, that a different pattern of interaction might be found for different relative constraint strengths than those used in these experiments. Future work will need to explore the generality of the particular interaction observed here.

Our studies investigated isolated single sentences, and it will be important to determine whether verb bias and within-sentence plausibility contribute similarly to the interpretation of sentences in discourse contexts, as well as how context itself contributes. Discourse context shares some of the features that make within-sentence plausibility likely to provide weaker constraints than frequency-based biases, leading to the prediction that verb bias would dominate the initial interpretation of temporarily ambiguous sentences in context just as it does in isolated sentences. Most of the studies so far embedding sentences in larger discourse contexts have examined the role of context itself rather than how it interacts with within-sentence factors such as lexical frequency-based biases or plausibility (e.g., Altmann & Steedman, 1988; Altmann et al., 1992; Britt, Perfetti, Garrod, & Rayner, 1992; Rayner, Garrod, & Perfetti, 1992; Spivey-Knowlton et al., 1993). Exceptions are studies by Britt (1994) and Boland (in press), and consistent with our prediction, both have found that lexical biases determine the extent to which discourse context affects interpretation. Also, Spivey-Knowlton and Tanenhaus (submitted) did not explicitly manipulate verb bias, but did find that bias was significantly correlated with the extent to which context aided interpretation. Clearly, more work needs to be done to map out the time course of context and within-sentence factors and their interactions. Such work remains one of the biggest challenges in comprehension research.

Finally, the use here of both moving window and eyetracking methodologies provides some evidence about their relative merits. A comparison of Figs. 1 and 4 shows that plausibility generally had more effect on first-pass times in Experiment 1 than on moving window times in Experiment 2, suggesting that eyetracking is more sensitive. Also, there was some evidence in the moving window reading times on the temporarily ambiguous NP in Experiment 2 suggesting that readers may have begun to anticipate sentential complement structures, but no similar pattern in Experiment 1. On the whole, though, the results obtained with the two techniques agreed fairly well.

In conclusion, the experiments reported here supported parallel interactive models of sentence comprehension over two-stage models. A range of results suggested that verb bias influenced processing as early as the word immediately following the verb (e.g., verb bias effects on *that* reading time and the lack of any plausibility effects on the NP after SC-bias verbs). If verb bias effects are due to revision, these results suggest that revision begins by the very next word, in which case it is difficult to see how lexical filtering and guidance accounts can be distinguished. It would be possible, however, to develop a two-stage model that could handle rapid effects of verb bias. In a serial lexical guidance model, lexical factors such as verb bias would determine the initial interpretation of an ambiguity, and then other factors such as plausibility would influence revision of that interpretation when necessary. Such a model could not, however, explain our finding that difficulty at the disambiguation increased in sentences with SC-bias verbs as the verb's likelihood of being used with direct objects increased, especially when the NP would be plausible as a direct object. In a serial lexical guidance model, the plausibility of the NP in an alternative analysis should be irrelevant in such sentences, since no revision should be necessary. Thus, the finding that graded effects of verb bias on reading times at the disambiguation depended on the plausibility of the NP as a direct object in sentences with both SC- and DO-bias verbs, together with the rapidity of verb bias effects, is most consistent with parallel interactive models of comprehension such as constraint satisfaction models.

Appendix A: Verbs Used in the Experiments

The verbs used in the experiments are presented below with their completion proportions from the norming study (Garnsey et al., in preparation). The proportions of direct object (DO) and sentential complement (SC) completions are given in the second and third columns below, followed by the proportion of the SC completions that included the complementizer *that* (*that*-preference and then all other types of completions. (*Acknowledged* and *estimated* were miscoded as EQ-bias, when *acknowledged* met the criterion for DO-bias verbs and *estimated* nearly did. Results were analyzed with the items containing these verbs coded both ways; see text.)

	Proportion of each completion type			
Verb	DO	SC	*that*-preference	Other
		DO-bias verbs		
accepted	0.98	0.01	1.00	0.01
advocated	0.79	0.05	1.00	0.16
asserted	0.64	0.31	0.94	0.05
confirmed	0.71	0.25	0.85	0.04
discovered	0.69	0.30	0.69	0.01
emphasized	0.75	0.19	0.68	0.06
established	0.94	0.06	1.00	0.00
heard	0.74	0.16	0.82	0.10
insured	0.84	0.13	0.85	0.03
maintained	0.74	0.23	0.80	0.03
printed	0.78	0.01	1.00	0.21
proposed	0.45	0.18	0.83	0.37
protested	0.58	0.11	0.92	0.31
understood	0.72	0.09	1.00	0.19
warned	0.74	0.11	0.83	0.15
wrote	0.87	0.00	1.00	0.13
		EQ-bias verbs		
acknowledged*	0.69	0.30	0.87	0.01
announced	0.49	0.48	0.69	0.03
conceded	0.26	0.33	0.91	0.41
confided	0.08	0.13	0.92	0.79
declared	0.44	0.52	0.71	0.04
denied	0.33	0.27	0.78	0.40
doubted	0.42	0.56	0.64	0.02
estimated*	0.61	0.33	0.76	0.06
feared	0.32	0.48	0.75	0.20
felt	0.12	0.11	0.55	0.77
guaranteed	0.46	0.50	0.62	0.04
guessed	0.39	0.25	0.64	0.56
knew	0.31	0.46	0.37	0.23
predicted	0.45	0.51	0.63	0.04
regretted	0.17	0.09	0.78	0.74
sensed	0.53	0.45	0.71	0.02

APPENDIX A—*Continued*

Verb	Proportion of each completion type: DO	SC	*that*-preference	Other
	SC-bias verbs			
admitted	0.09	0.60	0.64	0.30
argued	0.11	0.35	0.89	0.54
assumed	0.09	0.89	0.59	0.02
believed	0.14	0.50	0.61	0.36
claimed	0.06	0.69	0.59	0.25
concluded	0.14	0.80	0.83	0.06
confessed	0.18	0.45	0.71	0.37
decided	0.01	0.14	0.67	0.85
figured	0.08	0.46	0.53	0.46
implied	0.06	0.90	0.85	0.04
indicated	0.21	0.70	0.69	0.08
proved	0.23	0.61	0.60	0.16
realized	0.14	0.77	0.60	0.09
suggested	0.18	0.61	0.68	0.10
suspected	0.29	0.68	0.62	0.02
worried	0.01	0.24	0.69	0.75

APPENDIX B: EXPERIMENTAL SENTENCES

The rating of the postverbal noun as a direct object is shown in the right column (7 = most plausible). See the Materials section of Experiment 1 for details. The plausible direct object version of each item is listed first.

DO-bias items

The talented photographer *accepted* (that) the *money* could not be spent yet.	6.84
The talented photographer *accepted* (that) the *fire* could not have been prevented.	3.47
The newspaper editor *advocated* (that) the *truth* needed to be made public.	6.58
The newspaper editor *advocated* (that) the *town* needed to be cleaned up.	3.71
The concerned priest *asserted* (that) the *belief* would be hard to justify.	5.06
The concerned priest *asserted* (that) the *morning* would be a bad time.	2.08
The CIA director *confirmed* (that) the *rumor* should have been stopped sooner.	6.89
The CIA director *confirmed* (that) the *money* should have been managed better.	4.24
The scuba diver *discovered* (that) the *wreck* was caused by a collision.	6.88
The scuba diver *discovered* (that) the *headache* was caused by lack of oxygen.	2.74
The angry father *emphasized* (that) the *problems* were continuing to get worse.	6.42
The angry father *emphasized* (that) the *schools* were continuing to get worse.	3.71
The primary suspect *established* (that) the *alibi* had been a total lie.	6.33
The primary suspect *established* (that) the *gun* had been stolen from him.	2.18
The gossipy neighbor *heard* (that) the *story* had never actually been true.	6.53
The gossipy neighbor *heard* (that) the *house* had never actually been sold.	1.95
The new owners *insured* (that) the *house* would never get flooded again.	7.00

The new owners *insured* (that) the *river* would never flood their basement.	2.47
The confident engineer *maintained* (that) the *machinery* would be hard to destroy.	6.35
The confident engineer *maintained* (that) the *debate* would be easy to win.	3.00
The journal editor *printed* (that) the *article* had been slanderous to him.	6.75
The journal editor *printed* (that) the *media* had been irresponsible and cruel.	3.57
The art critic *wrote* (that) the *interview* had been a complete disaster.	6.11
The art critic *wrote* (that) the *painting* had been a clever forgery.	2.25
The surgical nurses *protested* (that) the *policy* were not fair to patients.	6.58
The surgical nurses *protested* (that) the *patients* were not being treated fairly.	3.12
The frustrated tourists *understood* (that) the *message* would mean they couldn't go.	6.31
The frustrated tourists *understood* (that) the *snow* would mean a late start.	2.63
The trained referees *warned* (that) the *spectators* would probably get too rowdy.	6.51
The trained referees *warned* (that) the *game* would probably go into overtime.	2.39
The lab technician *proposed* (that) the *idea* might be worth another try.	6.29
The lab technician *proposed* (that) the *water* might be contaminated with sewage.	2.32

EQ-bias items

The sales clerk *acknowledged* (that) the *error* should have been detected earlier.	6.95
The sales clerk *acknowledged* (that) the *shirt* should have been marked down.	3.76
The proud mother *announced* (that) the *wedding* would be a big event.	6.76
The proud mother *announced* (that) the *flowers* would be delivered at noon.	2.32
The defense attorney *conceded* (that) the *point* might come up in court.	6.29
The defense attorney *conceded* (that) the *client* might come apart in court.	3.47
The teenage girl *confided* (that) the *secret* had been really bothering her.	5.74
The teenage girl *confided* (that) the *stranger* had been following her earlier.	2.16
The new mayor *declared* (that) the *holiday* would be a festive occasion.	6.08
The new mayor *declared* (that) the *potholes* would be repaired in June.	1.38
The crooked politician *denied* (that) the *accusation* would change things at all.	6.83
The crooked politician *denied* (that) the *election* would change things at all.	3.49
The ice skater *doubted* (that) the *judges* would keep her from competing.	6.47
The ice skater *doubted* (that) the *storm* would keep people from coming.	3.59
The careful accountant *estimated* (that) the *taxes* could be kept low enough.	6.24
The careful accountant *estimated* (that) the *governor* could be persuaded to pay.	2.58
Mary Ann's mother *feared* (that) the *tantrums* would get worse and worse.	6.47
Mary Ann's mother *feared* (that) the *dress* would get torn and dirty.	3.65
The physical therapist *felt* (that) the *pain* would be easy to manage.	6.02
The physical therapist *felt* (that) the *answer* would be lots of exercise.	2.59
The sales department *guaranteed* (that) the *product* would go on sale soon.	6.79
The sales department *guaranteed* (that) the *noise* would go away quite quickly.	2.59
The desk clerk *guessed* (that) the *name* had been written very hastily.	6.26
The desk clerk *guessed* (that) the *party* had been planned months ago.	2.45
The famous novelist *knew* (that) the *material* would make some people unhappy.	6.79
The famous novelist *knew* (that) the *pause* would make her seem uncertain.	2.54
The publicity agent *predicted* (that) the *problem* would make life very difficult.	6.53
The publicity agent *predicted* (that) the *clothes* would make a big impact.	2.74
The senior senator *regretted* (that) the *decision* had ever been made public.	6.65
The senior senator *regretted* (that) the *reporter* had ever seen the report.	3.47

The skilled negotiator *sensed* (that) the *conflict* would probably not get resolved.	6.74
The skilled negotiator *sensed* (that) the *trip* would probably not go well.	3.94

SC-bias items

The ticket agent *admitted* (that) the *mistake* had been careless and stupid.	6.79
The ticket agent *admitted* (that) the *airplane* had been late taking off.	2.12
The divorce lawyer *argued* (that) the *issue* was irrelevant to the case.	6.53
The divorce lawyer *argued* (that) the *witness* was irrelevant to the case.	2.95
The office manager *indicated* (that) the *problem* would affect the whole office.	6.18
The office manager *indicated* (that) the *remark* would affect the whole office.	3.46
The job applicant *believed* (that) the *interviewer* had been dishonest with her.	6.37
The job applicant *believed* (that) the *appointment* had been set up already.	2.18
The weary traveler *claimed* (that) the *luggage* had been stolen in Rome.	6.89
The weary traveler *claimed* (that) the *attendant* had been rude and surly.	2.29
The account executive *concluded* (that) the *speech* had not gone very well.	6.39
The account executive *concluded* (that) the *bank* had not kept careful records.	2.45
The bank guard *confessed* (that) the *robbery* had been his own idea.	4.35
The bank guard *confessed* (that) the *vault* had been left open intentionally.	1.74
The cab driver *assumed* (that) the *blame* belonged to the other driver.	6.35
The cab driver *assumed* (that) the *car* belonged to the cab company.	2.26
The shrewd salesman *figured* (that) the *prices* would be going up soon.	6.42
The shrewd salesman *figured* (that) the *customers* would be paying in cash.	3.35
The union leader *implied* (that) the *raise* would keep them from striking.	4.95
The union leader *implied* (that) the *weather* would keep them from picketing.	2.29
The experienced judge *decided* (that) the *appeal* should be started right away.	6.24
The experienced judge *decided* (that) the *witness* should be warned about lying.	2.63
The careful scientist *proved* (that) the *theory* had not been sufficiently tested.	6.39
The careful scientist *proved* (that) the *journal* had not been rigorous enough.	3.87
The novice plumber *realized* (that) the *mistake* would cost someone some money.	6.41
The novice plumber *realized* (that) the *tool* would cost too much for him.	2.42
The film director *suggested* (that) the *scene* should be filmed at night.	5.93
The film director *suggested* (that) the *dirt* should be scattered all around.	2.51
The factory owner *suspected* (that) the *workers* would probably go on strike.	6.58
The factory owner *suspected* (that) the *cash* would probably not last long.	3.29
The bus driver *worried* (that) the *passengers* were starting to get annoyed.	6.41
The bus driver *worried* (that) the *tires* were starting to go flat.	1.74

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