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The parser doesn't ignore intransitivity, after all

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Abstract

Several previous studies (Adams, Clifton, & Mitchell, 1998; Mitchell, 1987; van Gompel & Pickering, 2001) have explored the question of whether the parser initially analyzes a noun phrase that follows an intransitive verb as the verb's direct object. Three eyetracking experiments examined this issue in more detail. Experiment 1 strongly replicated the finding (van Gompel & Pickering, 2001) that readers experience difficulty on this noun phrase in normal reading, and found that this difficulty occurs even with a class of intransitive verbs for which a direct object is categorically prohibited. Experiment 2, however, demonstrated that this effect is not due to syntactic misanalysis, but is instead due to disruption that occurs when a comma is absent at a subordinate clause/main clause boundary. Exploring a different construction, Experiment 3 replicated the finding (Pickering & Traxler, 2003; Traxler & Pickering, 1996) that when a noun phrase "filler" is an implausible direct object for an optionally transitive relative clause verb, processing difficulty results; however, there was no evidence for such difficulty when the relative clause verb was strictly intransitive. Taken together, the three experiments undermine the support for the claim that the parser initially ignores a verb's subcategorization restrictions.

Introduction

One of the central debates in research on language comprehension is about the nature of the information that a reader or listener uses to construct an initial syntactic analysis of word-by-word linguistic input. According to the "garden path" theory of Frazier and colleagues (Frazier, 1978, 1987; Frazier & Clifton, 1996; Frazier & Rayner, 1982), these syntactic decisions are made on the basis of structural information, with the parser constructing the analysis that is, in some well-defined sense, structurally simplest. On the other hand, theorists working within the "constraint satisfaction" framework (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998) have

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[2]In fact, Adams et al. did compute this measure (Chuck Clifton, p. c.), but did not report it in the published article since it did not suggest an effect on the postverbal noun phrase, and therefore did not add to the overall picture.

[3]It may be noted that in (8c), the reader could in principle adopt an analysis on which *the vet* is the subject of a relative clause, e.g., When the dog arrived at the clinic the vet owned, it started barking. In fact this analysis would have been possible for only a minority of the items. Furthermore, if readers did in fact adopt this analysis, inflated reading times would be expected upon disambiguation. There was no hint of such an effect.

[4]It is important to note that according to the standard syntactic analysis of relative clauses, the moved constituent is technically not the noun phrase that is modified by the relative clause (e.g., *the letter* in 12a–b), but instead it is the relative pronoun, e.g. *that*. However, for reasons that go well beyond the scope of this article, the plausibility relation that matters is the plausibility of the noun phrase as a direct object of the verb. See, e.g., Heim and Kratzer (1998, chapter 5) for a detailed analysis.

proposed that all potentially useful sources of information are available to guide the construction of a syntactic analysis, with the analysis that is actually constructed depending on the relative strengths of the information of various types. On this view, relevant information could be drawn from, for example, the wider discourse, the comprehender's knowledge of the frequency of different structures, and the comprehender's knowledge of semantic or syntactic restrictions imposed by specific lexical items. The two positions are in agreement that such information does ultimately play a role in determining how the reader or listener analyzes a sentence's syntactic structure; what is at issue is whether this information plays an immediate role, or whether it affects only a later stage of processing during which an incorrect initial analysis can be revised (Rayner, Carlson, & Frazier, 1983).

Much of the experimental work that has been designed to test the predictions of these two views has focused on whether verb-specific information guides the initial syntactic analysis of material that is potentially an argument of the verb. This research has asked whether the parser's analysis of this material depends on the thematic restrictions that the verb imposes on its arguments (e.g., animacy; Ferreira & Clifton, 1986; Trueswell, Tanenhaus, & Garnsey, 1994; Clifton, Traxler, Mohamed, Williams, Morris, & Rayner, 2003) and on the frequency with which the verb appears with complements of various syntactic types (e.g., noun phrase or finite clause; Ferreira & Henderson, 1990; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Kennison, 2001; Pickering, Traxler, & Crocker, 2000; Trueswell, Tanenhaus, & Kello, 1993). It is probably safe to say that the jury is still out: while there is a considerable body of experimental work supporting the view that such verb-specific information can influence the initial parse of a sentence, there is also evidence that structural preferences predicted by the garden path theory can persist even in the face of rather strong thematic or frequency information from the verb that would tend to support an alternate analysis.

The topic of the present article is a finding first reported by Mitchell (1987) that would seem to provide very strong evidence against the constraint satisfaction position. In a self-paced reading study, Mitchell (1987) presented sentences like the following, in which the noun phrase following a subordinate clause verb is the subject of the main clause:

(1)

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

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

The question of interest was whether readers would initially attempt to analyze *the doctor* as the direct object of *sneezed* in (1a), or whether this option would be closed off before processing *the doctor* by the fact that *sneezed* is an intransitive verb. In Mitchell's experiment the sentences were presented in two separate segments, and in the critical conditions the break between segments came after the critical noun phrase (*the doctor*). The second region of (1b) took longer to read than the second region of (1a), reflecting the fact that the reader does initially analyze *the doctor* as the direct object of *visited*, and must revise this analysis upon reaching the main clause verb (*prescribed*), which cannot be attached into the phrase marker given this initial analysis. This result is unsurprising, since it is consistent with numerous experiments demonstrating a strong preference to analyze an

ambiguous post-verbal noun phrase as the verb's direct object when the verb allows a transitive frame (e.g., Frazier & Rayner, 1982; Christianson, Hollingworth, Halliwell, & Ferreira, 2001). However, Mitchell also found a very large (about 700 ms) effect on the first region, in the opposite direction, with faster reading times on (1b) than on (1a). The extra reading time on the first region of (1a) apparently reflected processing difficulty resulting from an initial parse on which the postverbal noun phrase was the direct object of the intransitive verb *sneezed*. In other words, it appeared that readers treated *the doctor* as the direct object of both *sneezed* and *visited*; the difference between the two cases was in the point at which reanalysis was forced. In (1a) the ungrammaticality of *sneezed the doctor* forced an almost immediate reanalysis, while in (1b) readers did not realize that their initial analysis was incorrect until they reached the main clause verb.

This result challenges the constraint satisfaction position because the syntactic analysis on which *the doctor* is the direct object of *sneezed* would seem to conflict with the strongest possible type of verb-specific information. The general preference for the subordinate clause object analysis of a post-verbal noun phrase over the main clause subject analysis is predicted by the garden path theory, as an instance of the preference for “late closure” over “early closure” (Frazier, 1978, 1987). In the Mitchell (1987) experiment, it appears that readers were applying this structural preference despite the fact that information about the types of syntactic complements with which the verb can appear (i.e., *subcategorization* information) could have ruled it out altogether. While the garden path theory is not committed to the claim that the parser ignores subcategorization information, the possibility that the parser applies its structural preferences without taking this information into account is consistent with the theory. In fact, in at least one published article, Frazier (1989) does suggest that this is likely to be the case, citing the Mitchell (1987) data as evidence. In sum, if verbal subcategorization information constrains the parser's initial structural analysis, this is consistent with (a version of) the garden path theory, as well as with the constraint satisfaction position; but if the parser initially ignores verbal subcategorization information, this is consistent only with the garden path theory.

Several commentators (e.g. Fodor, 1989) suggested an artifactual interpretation of Mitchell's result. Participants in the experiment saw, as the first segment of (1a), the fragment *After the child had sneezed the doctor*. It is possible that participants unconsciously regard segmentation in self-paced reading as a clue to syntactic constituency, and that this heuristic is strong enough to induce a preference that would not otherwise exist for a direct object attachment of *the doctor*. Motivated by this concern, Adams, Clifton, and Mitchell (1998) attempted to replicate Mitchell's (1987) finding using eyetracking rather than self-paced reading. This change of methodology eliminated the potential influence of segmentation, since in the eyetracking paradigm the entire sentence is visible at once and the participant's task is simply to read the sentence in a normal manner. The Adams et al. experiment used four conditions, crossing the transitivity of the subordinate clause verb with the presence or absence of a disambiguating adverbial between this verb and the subsequent noun phrase:

(2)

a. After the dog struggled the veterinarian took off the muzzle.

b. After the dog struggled pathetically the veterinarian took off the muzzle.

c. After the dog scratched the veterinarian took off the muzzle.

d. After the dog scratched pathetically the veterinarian took off the muzzle.

Again, there was evidence of disruption at the main clause verb in sentences like (2c), in the form of elevated reading times beginning on this verb. No difficulty on the main clause verb appeared when the presence of the adverb signalled a clause boundary, as in (2d). Crucially, Adams et al. found essentially no increase in reading time on the main clause subject when it followed an intransitive subordinate clause verb in (2a), compared to any of the other conditions. Adams et al. interpreted these results as supporting an interpretation of Mitchell's data emphasizing the role of methodological artifact, and as undermining the evidence for the claim that readers ignore subcategorization information in constructing an initial parse.[1]

However, van Gompel and Pickering (2001) performed an experiment designed to test whether the lack of an effect on the critical noun phrase in the Adams et al. (1998) study might have been due to limitations of the materials and statistical analyses in that experiment. Adams et al., like Mitchell, had used a two-word noun phrase as the critical region. van Gompel and Pickering speculated that this phrase might not have been long enough for the full effect of any disruption to appear in the eyetracking record. Furthermore, they pointed out that Adams et al. did not report regression path duration (the sum of fixations from entering a region to first exiting it to the right, including time spent re-reading earlier portions of the sentence; this is also known as go-past time), and thereby overlooked any effect of regressive eye movements that might have occurred when the noun phrase followed an intransitive verb.[2] To correct these potential problems, they replicated the study using sentences such as (3a–b):

(3)

a. After the dog struggled the vet and his new assistant took off the muzzle.

b. After the dog scratched the vet and his new assistant took off the muzzle.

Unlike Adams et al., van Gompel and Pickering did find increased difficulty on the post-verbal noun phrase when it followed an intransitive subordinate clause verb, as in (3a). This took the form of increased go-past time on both the region immediately following the verb (*the vet*) and the subsequent region (*and his*). First-pass time was also 22 ms longer on *the vet* in sentences like (3a), though this difference did not quite reach significance.

The eyetracking experiments presented in this article were designed to help settle the question of whether the parser may in fact attempt to attach a noun phrase as the direct object of an intransitive verb. Clearly, the previous research on this question is less than definitive. The Mitchell (1987) experiment gives a very strong positive answer, but methodological artifact is likely to have played at least some role. The two eyetracking

[1]It is worth noting that Mitchell (1987) also included conditions in which an adverbial intervened between the subordinate clause verb and the ambiguous noun phrase, as in (2b) and (2d). This noun phrase was then followed by the frame break. When the verb was transitive, this condition induced a significant increase in reading time on both the first and second frames; it appears that this presentation may have rendered the sentence nearly incomprehensible.

studies give a split verdict, with the reasons for the different results being less than perfectly clear. In addition, even if the van Gompel and Pickering (2001) positive finding is reliable, several alternate explanations remain to be considered. First, it could be argued that many of the intransitive verbs used in the studies described above are not strictly intransitive (cf. Ferreira & McClure, 1997). To deal with this issue, Experiment 1 explored the behavior of so-called *unaccusative* intransitives (Levin & Rappaport Hovav, 1995; Perlmutter, 1978) in the same construction used in the previous studies. The underlying syntax of unaccusatives categorically rules out a direct object in the surface representation. Second, it is possible that the increased processing cost found on the potentially ambiguous noun phrase in sentences like (1a) and (3a) is due to a cost incurred when a new clause is initiated. Third, it is possible that this processing cost is due to the absence of a comma at the clause boundary. Experiment 2 was designed to test both of these hypotheses. Finally, Experiment 3 investigated whether the parser attempts an illegal direct object analysis in a long-distance dependency construction in which the critical noun phrase is encountered prior to an intransitive verb.

Experiment 1

Because the primary goal of Experiment 1 was to determine whether the results obtained by van Gompel and Pickering (2001) are reliable, the materials and design of the present experiment are very similar to this predecessor experiment. However, the present experiment was also motivated by the observation that the intransitive verbs used in all three of the studies discussed above (Adams et al., 1998; Mitchell, 1987; van Gompel & Pickering, 2001) consisted of a mix of two types of intransitive verbs that are distinguished by both syntactic and semantic properties, so-called *unaccusatives* (e.g., *arrive*, *appear*) and *unergatives* (e.g., *sneeze*, *laugh*; Levin & Rappaport Hovav, 1995; Perlmutter, 1978). The relevant point for present purposes is that while a direct object is categorically prohibited with unaccusative verbs, there are specific constructions in which a direct object can appear with unergative verbs. Examples of these constructions, the so-called *cognate object*, *its way*, and *resultative* constructions, are in (4a–c) below:

(4)

a. The sailor laughed a hearty laugh.

b. The speaker laughed her way onto the podium.

c. The child sneezed the paper off the table.

With unaccusative verbs, the corresponding constructions are ungrammatical:

(5)

a. *The sailor arrived a recent arrival.

b. *The speaker arrived her way onto the podium.

c. *The magician appeared the rabbit out of the hat.

A detailed account of the syntactic behavior of these two classes of verbs goes well beyond the scope of this paper. (For such a discussion, including both the syntactic and semantic

aspects of the distinction, see Alexiadou, Anagnostopoulou, & Everaert, 2004, and Levin & Rappaport Hovav, 1995.) Very briefly, a standard account of the distinction claims that for unaccusative verbs, the single argument of the verb (e.g., *the sailor* in 5a), is actually base-generated in object position, but moves to subject position both because the sentence requires a subject and because the verb lacks certain properties necessary for assigning accusative case to a noun phrase (Burzio, 1986). As a result, an overt direct object can never appear, because the object position is blocked by a trace of movement and because the verb is still incapable of assigning accusative case. With unergative verbs, on the other hand, the single argument of the verb is base-generated in subject position, and the verb is capable, in principle, of assigning accusative case. Closely related to this distinction is the fact that the subject of an unaccusative verb is not the cause or agent of the event denoted by the verb, but rather the theme or patient, while the subject of an unergative verb can indeed be construed as the cause or agent of this event.

Van Gompel and Pickering (2001) did concede the existence of constructions like (4a–c) above in which their intransitive verbs could take a direct object. They wrote:

> The existence of these constructions makes it impossible for us to conclude that people initially ignore subcategorization restrictions, because it is possible that readers might have initially assumed that the supposedly intransitive verb actually took a direct object as part of one of these rare constructions. However, our results do indicate that the processor initially ignores extremely strong subcategorization preferences. (p. 855)

Across the three previous studies discussed above, approximately two-thirds of the intransitive verbs were unergatives, and therefore could, in principle, appear with an overt direct object. In the present experiment, two conditions were created from the single intransitive condition, one with an unaccusative verb and one with an unergative. The goal was to determine whether the parser is affected by the underlying syntax of the intransitive verb, or whether it attempts a direct object analysis in both cases. A distinct possibility was that the parser would attempt the direct object analysis only with unergatives, since by the time the reader's eyes leave an unaccusative verb, there may simply be no available slot for a direct object in the phrase marker that the parser has built.

In some languages, the unaccusative/unergative distinction is encoded overtly. For example, in languages such as French and Italian that use an auxiliary verb in perfective constructions, this auxiliary is generally *have* in the case of unergatives and *be* in the case of unaccusatives. In English, however, various subtle and interrelated diagnostic tests are necessary to determine whether an intransitive verb is in fact an unaccusative or an unergative. Levin and Rappaport-Hovav (1995) have written a book-length treatment of these various diagnostics, and have classified intransitive verbs accordingly. In developing the materials for this experiment, Levin and Rappaport-Hovav's (1995) classifications were used to select verbs from the two classes.

Method

Participants—Thirty-six native speakers of American English, who were members of the University of Massachusetts community, were given course credit or were paid $5 to participate in the experiment. All had normal or corrected-to-normal vision, and all were naïve to the purpose of the experiment.

Materials—The experimental materials consisted of 24 sets of sentences like (6a–c).

(6)

a. When the dog arrived the vet and his new assistant took off the muzzle.

b. When the dog struggled the vet and his new assistant took off the muzzle.

c. When the dog scratched the vet and his new assistant took off the muzzle.

These sentences were modified versions of the materials used by van Gompel and Pickering (2001). The only difference between versions was the subordinate clause verb; versions (a–c) will be referred to as the *unaccusative*, *unergative*, and *transitive* conditions, respectively. Whenever possible, the verbs used by van Gompel and Pickering were preserved in the present experiment, with the addition of a third condition. As noted above, Levin and Rappaport-Hovav's (1995) classifications of individual verbs as unaccusative or unergative were used to select the verbs in each of the intransitive conditions. Four unaccusative verbs (*arrived*, *departed*, *erupted*, *remained*) were each used in two different items, with the experimental lists arranged so that no participant saw any verb more than once. The three sets of verbs did not differ significantly in length, with mean lengths of 7.58, 7.13, and 7.25 characters in the unaccusative, unergative, and transitive conditions, respectively ($F(2, 69) = .425$, $p = .66$). They also did not differ significantly in frequency, with respective mean frequencies of 5481, 2334, and 8271 in the 131-million word HAL corpus (Burgess & Livesay, 1998) ($F(2, 69) = 1.13$, $p = .33$). The full set of materials is presented in the Appendix.

The items were separated into three lists, arranged so that one version of each item appeared on each list, with eight from each experimental condition. Each participant was randomly assigned to one of the three lists. The 24 experimental sentences were intermixed with 118 filler sentences of various types. These included ten sentences that had a subordinate clause/main clause structure, but in which the noun phrase that followed the subordinate clause verb was, in fact, the subordinate clause object. As in the experimental sentences, there was no comma at the clause boundary in these fillers. The remainder of the filler sentences consisted of a single clause. The 142 sentences were presented in an individually randomized order to each participant, after eight practice trials.

Procedure—Participants were tested individually, and eye movements were recorded using a Fourward Technologies Dual Purkinje Image eyetracker, interfaced with an IBM compatible computer. The sampling rate was 1000 Hz. Viewing was binocular, but only the right eye was monitored. All sentences in this experiment were displayed on a single line with a maximum length of 80 characters. Stimuli were displayed on a 15-inch NEC MultiSync 4FG monitor. Participants were seated 61cm from the computer screen. At this

distance, 3.8 characters subtended 1° of visual angle; the eyetracker has an angular resolution of less than 10 min of arc.

On arrival at the laboratory, participants were given instructions and had a bite bar prepared for them that served to stabilize the head. A calibration routine was performed, and its accuracy was checked after each sentence. Participants were instructed to read the sentences for understanding, and to read at a normal rate. After reading each sentence, the participants pressed a button to remove the sentence. Comprehension was checked on approximately 30% of all trials during the experiment by presenting the participant with a yes/no question. Average accuracy for the comprehension questions was above 85%, with no participant scoring below 75%. The entire experiment lasted approximately 30 minutes.

Results and Discussion

For the purpose of analysis, each sentence was divided into six regions as shown below, separated by slashes (/). The material that varied by condition is separated by the vertical pipe (|).

(7) When the dog/ arrived| struggled| scratched/ the vet /and his/ new assistant/ took off the muzzle.

The regions will be referred to as the initial region (*When the dog*), the verb region (*arrived*|*struggled*|*scratched*), ambiguous region 1 (*the vet*), ambigous region 2 (*and his*), ambiguous region 3 (*new assistant*), and the final region (*took off the muzzle*). Ambiguous region 1 consisted of the material up through the head noun of the post-verbal noun phrase. (This noun varied in length from three to ten characters; the head noun in example (7) is therefore somewhat atypical in its length.) Ambiguous region 2 consisted of the next two words. The final region began with the disambiguating verb. The use of the name “ambiguous region” is, of course, question-begging with respect to whether there is in fact a syntactic ambiguity in the unaccusative and unergative versions.

Four reading time measures were computed: *first fixation duration*, *first pass time* (which is referred to as *gaze duration* when discussing single-word regions), *go-past time*, and *percent regressions* (Rayner, 1998). First fixation duration is simply the duration of the first fixation in a region, whether it is the only fixation in the region or the first of multiple fixations. This measure is often used with single-word regions as an index of lexical processing difficulty (e.g., Reichle, Rayner, & Pollatsek, 2003). However, it has also been shown to be sensitive to difficulty associated with syntactic disambiguation (e.g., Frazier & Rayner, 1982). In the present experiment, this measure is of interest primarily on ambiguous region 1 and on the final region, where processes of syntactic disambiguation might be operative in one or more of the experimental conditions. For completeness, however, this measure is reported for all regions. First pass time is the sum of all fixations in a region prior to leaving the region for the first time, either to the left or the right. As noted above, go-past time is the sum of fixations from first fixating the region until the reader leaves the region to the right, including any time spent to the left of the region after a regressive eye movement and any time spent rereading material in the region before moving on. The percent regressions measure gives the probability that a reader makes a regressive eye movement after fixating

the region. This measure includes only regressions made during the reader's first pass through the region; it does not include regressions made after re-fixating the region. Effects of syntactic reanalysis are often apparent in the go-past and regression measures. (See Staub & Rayner, in press, for more detailed discussion of the interpretation of these and other eye movement measures.)

Prior to all analyses, sentences with track losses were excluded (less than 2% of trials). In addition, fixations less than 80 ms in duration, and within one character of the previous or subsequent fixation, were incorporated into this neighboring fixation. Remaining fixations of less than 80 ms were deleted, as were fixations of longer than 800 ms. It is assumed that readers do not extract useful information from fixations shorter than 80 ms (see Rayner & Pollatsek, 1989), and that fixations longer than about 800 ms are likely to reflect track losses or other anomalous events. Less than 2% of all fixations were eliminated.

Table 1 presents the participant means on each measure for each region, as well as the standard errors of the participant means. For each test of differences between means, analyses of variance (ANOVAs) were performed with participants (F_1) and items (F_2) as random effects variables. Pairwise comparisons of condition means were performed when the ANOVAs indicated that significant differences between conditions were present.

No differences between conditions approached significance on either the initial region or the verb region. On ambiguous region 1 (*the vet*), the differences in first fixation duration did not approach significance. However, there were significant differences between conditions in first pass time ($F_1(2,70) = 6.03$, $p < .01$; $F_2(2, 46) = 3.60$, $p < .05$), and go-past time ($F_1(2,70) = 9.65$, $p < .001$; $F_2(2, 46) = 6.49$, $p < .01$). There was also a significant difference in the percent regressions measure in the participants analysis, though this difference was marginal in the items analysis ($F_1(2,70) = 5.12$, $p < .01$; $F_2(2, 46) = 3.10$, $p = .055$). Pairwise comparisons revealed that the unaccusative condition and the unergative conditions did not differ significantly from each other on either the first pass or go-past measures (*p*s > .5). Readers spent longer on this region in the unaccusative condition than in the transitive condition, as measured by both first pass time (433 ms vs. 389 ms; $t_1(35) = 3.18$, $p < .01$, $t_2(23) = 2.48$, $p < .05$) and go-past time (493 ms vs. 419 ms; $t_1(35) = 3.75$, $p < .01$, $t_2(23) = 2.49$, $p < .05$). Similarly, they spent longer on this region in the unergative condition than in the transitive condition, as measured by both first pass time (426 ms vs. 389 ms; $t_1(35) = 2.82$, $p < .01$, $t_2(23) = 2.77$, $p < .02$) and go-past time (504 ms vs. 419 ms; $t_1(35) = 4.07$, $p < .001$, $t_2(23) = 3.64$, $p < .01$). On the percent regressions measure, the two intransitive conditions did not differ from each other (*p*s > .15). There were marginally more regressions in the unaccusative condition than in the transitive condition in the participants analysis, though this difference was not significant in the items analysis (9.2% vs. 5.3%; $t_1(35) = 2.00$, $p = .054$, $t_2(23) = 1.25$, $p = .23$). There were significantly more regressions in the unergative condition than in the transitive condition (12.4% vs. 5.3%; $t_1(35) = 2.87$, $p < .01$, $t_2(23) = 2.27$, $p < .05$).

On ambiguous region 2 (*and his*), there were no significant differences on either the first fixation or first pass measures. However, there was a go-past effect that was significant by participants and marginal by items ($F_1(2,70) = 5.69$, $p < .01$; $F_2(2, 46) = 3.00$, $p = .06$). In

addition, there was a significant difference in percent regressions ($F_1(2,70) = 7.66$, p < .01; $F_2(2, 46) = 5.46$, $p < .01$). Reading times on the go-past measure were significantly longer in the unaccusative condition than in the unergative condition (433 ms vs. 383 ms; $t_1(35) = 3.17$, $p < .01$, $t_2(23) = 2.16$, $p < .05$), while the comparison between the unaccusative and transitive conditions was significant in the participants analysis and marginal in the items analysis (433 ms vs. 377 ms; $t_1(35) = 2.59$, $p < .02$, $t_2(23) = 1.86$, $p = .075$). The unergative and transitive conditions did not differ, *p*s > .5. There were somewhat more regressions in the unaccusative condition than in the unergative condition (10.7% vs. 6.8%), and this difference was marginal by participants and significant by items ($t_1(35) = 1.88$, $p = .07$, $t_2(23) = 2.11$, $p < .05$). The difference in regressions between the unaccusative and transitive conditions (10.7% vs. 3.1%) was fully significant ($t_1(35) = 3.67$, $p < .01$, $t_2(23) = 3.01$, $p < .01$). Finally, the difference between the unergative and transitive conditions (6.8% vs. 3.1%) was significant by participants, but not by items ($t_1(35) = 2.25$, $p < .05$, $t_2(23) = 1.45$, $p = .16$).

There were no differences that approached significance on ambiguous region 3. On the final, disambiguating region (*took off the muzzle*), there were no significant differences on the first fixation measure, but there were significant effects in first pass time (F_1 (2,70) = 5.12, $p < .01$; F_2 (2, 46) = 4.48, $p < .02$), go-past time (F_1 (2,70) = 10.16, $p < .001$; F_2 (2, 46) = 16.65, $p < .001$), and percent regressions (F_1 (2,70) = 8.45, $p < .01$; F_2 (2, 46) = 15.94, $p < .001$). On the first pass measure, the only significant difference was between the unergative and transitive conditions (831 vs. 929 ms; $t_1(35) = 3.21$, $p < .01$, $t_2(23) = 3.01$, $p < .01$), with the unaccusative mean falling between these two (874 ms) and not differing significantly from either one (*p*s > .10). On the go-past measure the pattern was clearer, with the transitive condition resulting in much longer reading times than either the unaccusative condition (1449 ms vs. 1046 ms; $t_1(35) = 2.93$, $p < .01$, $t_2(23) = 3.47$, $p < .01$) or the unergative condition (1449 ms vs. 938 ms; $t_1(35) = 3.61$, $p < .01$, $t_2(23) = 5.24$, $p < .001$). The two intransitive conditions did not differ significantly ($t_1(35) = 1.74$, $p = .09$, $t_2(23) = 1.94$, $p = .06$). A similar pattern emerged on the percent regressions measure, with more regressions in the transitive condition than in either the unaccusative condition (22.1 % vs. 9.1%; $t_1(35) = 2.95$, $p < .01$, $t_2(23) = 4.70$, $p < .001$) or the unergative condition (22.1% vs. 8.1%; $t_1(35) = 3.48$, $p < .01$, $t_2(23) = 5.01$, $p < .001$). Again, the two intransitive conditions did not differ (*p*s > .5).

These results are easily summarized. There was evidence in the form of an increase in regressive eye movements and a corresponding increase in go-past time that readers experienced difficulty when they encountered the disambiguating main clause verb in the transitive condition. This is consistent with the assumption that the ambiguous noun phrase is indeed preferentially analyzed as the object of the subordinate clause verb, when this verb allows such an analysis, and that the direct object analysis is maintained until clearly disambiguating material is encountered. Of greater present interest, however, is the fact that clear signs of processing difficulty were evident on the post-verbal noun phrase itself in the intransitive conditions: both first-pass time and go-past time were significantly inflated on the first few words of this phrase, compared to the transitive condition. This clearly

replicates van Gompel and Pickering's (2001) main finding. In fact, while their study found a significant effect in go-past time, it found only a nonsignificant trend in first pass time.

The unaccusative and unergative conditions did not show any signs of differing on ambiguous region 1. Evidently, processing difficulty on this region does not depend on the existence of a possible, if highly infrequent, transitive frame with unergative verbs, since the same effect appeared with unaccusative verbs, and with these verbs an overt direct object is ruled out by the underlying syntax. To the extent that these conditions differed at all, it was in the direction of *greater* processing difficulty for sentences with unaccusatives on the next region, ambiguous region 2.

In sum, Experiment 1 confirms that when the subordinate clause verb is intransitive, processing difficulty appears on a subsequent noun phrase in normal reading. Given that this result has now been obtained by van Gompel and Pickering (2001) and in two different conditions in the present experiment, an obvious question is why this effect was not obtained by Adams, Clifton, and Mitchell (1998). There does not seem to be a compelling answer to this question. van Gompel and Pickering suggested that because Adams et al. (1998) used a rather short ambiguous noun phrase, readers may have had parafoveal preview of the disambiguating material while still fixating the ambiguous material, and that this may have helped them to resolve the syntactic ambiguity very rapidly. However, the one explicit attempt in the literature to determine whether parafoveal preview of disambiguating information is able to influence readers' syntactic analysis of ambiguous material (Clifton et al., 2003) did not find any evidence that this was the case. Consequently, this suggestion does not seem likely to be correct. It is of course possible that the Adams et al. (1998) result was simply a Type II error, though this is an unsatisfying explanation for the differences between experiments.

Experiment 2

The goal of Experiment 2 was to evaluate two explanations for the effects obtained by van Gompel and Pickering (2001) and in Experiment 1. These explanations do not assume that the parser adopts an initial analysis according to which a post-verbal noun phrase is the direct object of an intransitive verb. The first of these (which was considered, but not tested, by van Gompel and Pickering) is that there is, very generally, a processing cost associated with initiating the main clause in the structure tested. The existence of increased reading times at a clause boundary is well-attested in the eye movement literature (Hill & Murray, 2000; Hirotani, Frazier, & Rayner, 2006; Rayner, Kambe, & Duffy, 2000), though this increase has been reported at the end of a clause where the boundary is marked by a comma, rather than at the beginning of the new clause. Nevertheless, it is possible that there is also a reading time cost associated with initiating a new clause. The second explanation is that there is a processing cost associated with beginning the main clause in the absence of a comma. In a written production task, Argaman and Mendelsohn (2000) found a fairly strong preference to use a comma at the boundary between a subordinate clause and a main clause, with 78% of the elicited sentences including a comma. Juliano and Tanenhaus (1994) also found a 90% rate of comma use at this clause boundary in the Wall Street Journal corpus (though this figure may be inflated by journalists' use of explicit style guidelines). It is

possible, therefore, that readers slow down on the critical noun phrase not because they have misanalyzed this phrase as the object of the preceding verb, but because they have correctly analyzed this phrase as the subject of the main clause, and have noted what they take to be infelicitous punctuation.

To test these hypotheses, materials with the same syntactic structure as in Experiment 1 were used in Experiment 2. The subordinate clause verb was always intransitive, and two factors were varied: the presence or absence of a comma, and the presence or absence of additional material within the subordinate clause following the verb:

(8)

a. When the dog arrived the vet and his assistant went home.

b. When the dog arrived, the vet and his assistant went home.

c. When the dog arrived at the clinic the vet and his assistant went home.

d. When the dog arrived at the clinic, the vet and his assistant went home.

The material that followed the subordinate clause verb was usually a prepositional phrase, as in the above example, though in a few items it was an adverb. Conditions (a–d) will be referred to as the *short no comma* condition, *short comma* condition, *long no comma* condition, and *long comma* conditions, respectively.

If the effect obtained in Experiment 1 is indeed due to the parser's misanalysis of the post-verbal noun phrase as a direct object, an interaction effect should appear in the present experiment. Longer reading times on *the vet and his assistant* would be expected in the short no comma condition than in the short comma condition, since in the latter case the possibility of a direct object analysis is eliminated. However, the direct object analysis is ruled out in the long conditions whether the comma is present or not, so no difference would be expected in the long conditions based on the presence or absence of a comma. (The assumption that the direct object analysis is ruled out by the presence of material intervening between the subordinate clause verb and the subsequent noun phrase is supported by the results obtained by Adams et al. (1998); as noted above, there were no signs of garden-pathing with sentences like (2d).) On the other hand, if the effect obtained in Experiment 1 is due to a general cost associated with beginning the main clause, then there should be no effect of the comma and no interaction between comma and length; with the possible exception of a length effect, no differences between conditions should be observed. Finally, if the effect is due to the cost of initiating the main clause in the absence of a comma, then reading times should be inflated in both of the no comma conditions, and the effect of the comma should not interact with the length variable.[3]

Method

Participants—Thirty-two native speakers of American English, who were members of the University of Massachusetts community, were given course credit or were paid $7 to participate in the experiment. (The compensation rate for participants in our laboratory was increased shortly after Experiment 1 was completed.) All had normal or corrected-to-normal

vision, and all were naïve to the purpose of the experiment. None of the participants in this experiment had participated in Experiment 1.

Materials—The experimental materials consisted of 24 sets of sentences like (8a–d) above. Half of the 24 items had an unaccusative subordinate clause verb, and half had an unergative. Given the results of Experiment 1, this between-items factor was not expected to influence the results. Supplementary analyses indicated that this was indeed the case, so all reported results are collapsed across item type.

The four versions of each item were separated into four lists, arranged so that one version of each item appeared on each list, with six from each experimental condition. Each participant was randomly assigned to one of the four lists. The 24 experimental sentences were intermixed with 118 filler sentences of various types. The structure of the fillers was similar to Experiment 1; 42 of the 118 fillers were the same as in Experiment 1. The 142 sentences were presented in an individually randomized order to each participant, after eight practice trials.

Procedure—The procedure was identical to Experiment 1. Participants averaged 93% correct on the comprehension questions, with no participant scoring below 80%. The duration of the experiment was 30 minutes.

Results and Discussion

For the purpose of analysis, each sentence was divided into five regions as shown below, separated by slashes (/). The material that varied by condition is separated by the vertical pipe (|).

(9) When the dog/ arrived| arrived,| arrived at the clinic| arrived at the clinic,/ the vet/ and his assistant/ went home.

The regions will be referred to as the initial region (*When the dog*), the verb region (*arrived*|*arrived*,|*arrived at the clinic*|*arrived at the clinic*,), ambiguous region 1 (*the vet*), ambigous region 2 (*and his assistant*), and the final region (*went home*). As in Experiment 1, the noun in ambiguous region 1 ranged from three to ten characters. Ambiguous regions 2 and 3 from Experiment 1 were collapsed into a single region, since the length of this material was shortened somewhat in this experiment in order to fit each sentence onto a single line.

The same four reading time measures were computed as in Experiment 1. Less than 3.5% of trials were deleted due to track losses, and less than 2.5% of remaining fixations were deleted due to falling outside the 80–800 ms range.

Table 2 presents the participant means on each measure for each of the regions, as well as the standard errors of the participant means. As in Experiment 1, ANOVAs were performed with participants (F_1) and items (F_2) as random effects variables. The presence or absence of a comma and subordinate clause length were each treated as within-participants or within-items factors.

On the initial region, there was an unexpected effect of length on the duration of the first fixation, with longer fixation times in the short conditions (223 ms vs. 211 ms; $F_1(1, 31) = 12.03$, $p < .01$, $F_2(1, 23) = 8.31$, $p < .01$). Given that all four conditions were identical for at least the first three words of the sentence, this effect is difficult to interpret, and in any event there was no hint of a similar first pass effect on this region. The effect of the comma and the interaction effect did not approach significance. On the verb region, there was of course a highly significant effect of length on first pass time (721 ms vs. 330 ms; $F_1(1, 31) = 415.68$, $p < .001$, $F_2(1, 23) = 332.29$, $p < .001$) and go-past time (758 ms vs. 348 ms; $F_1(1, 31) = 460.32$, $p < .001$, $F_2(1, 23) = 262.22$, $p < .001$). There were no significant effects of the comma and no interaction effects. There were no signs of effects on the first fixation or regressions measures on this region.

On ambiguous region 1 (*the vet*), there were no significant effects of length on the reading time measures. There was a marginal effect of length on the regressions measure, with more regressions in the short conditions (6.6 % vs. 3.4%; $F_1 (1, 31) = 3.42$, $p = .07$, $F_2(1, 23) = 2.57$, $p = .12$). However, there were highly significant effects of the comma on all three reading time measures, with longer reading times when the comma was absent (First fixation: 283 ms vs. 267 ms; $F_1(1, 31) = 8.98$, $p < .01$, $F_2(1, 23) = 6.44$, $p < .02$. First pass: 392 ms vs. 358 ms; $F_1(1, 31) = 10.35$, $p < .01$, $F_2(1, 23) = 11.76$, $p < .01$. Go-past: 449 ms vs. 381 ms; $F_1(1, 31) = 17.10$, $p < .001$, $F_2(1, 23) = 20.15$, $p < .001$.). There were also more regressions from this region when the comma was absent (7.1% vs. 3.4%), though this difference was fully significant only by participants ($F_1(1, 31) = 5.71$, $p < .05$, $F_2(1, 23) = 3.41$, $p = .08$). There was no hint of an interaction effect on any measure (all ps > .2).

On ambiguous region 2 (*and his assistant*), there was no effect of length on the duration of the first fixation, but there was a significant effect on first pass time, with longer reading times in the short condition (562 ms vs. 519 ms; $F_1(1, 31) = 6.79$, $p < .02$, $F_2(1, 23) = 12.48$, $p < .01$). The same pattern held in go-past time, though the effect was fully significant only by participants (614 ms vs. 566 ms; $F_1(1, 31) = 5.22$, $p < .05$, $F_2(1, 23) = 3.72$, $p = .07$). There were slightly, but not significantly, more regressions in the long condition (5.8% to 3.5%; $F_1(1, 31) = 2.93$, $p = .10$, $F_2(1, 23) = 2.13$, $p = .16$). There were no significant effects of the comma on first fixation or first pass (ps > .2). However, there was a significant effect on go-past time, with longer times when the comma was absent (622 ms vs. 559 ms; $F_1(1, 31) = 5.20$, $p < .05$, $F_2(1, 23) = 7.98$, $p < .02$). There were also more regressions when the comma was absent (7.6% to 1.8%; $F_1(1, 31) = 15.71$, $p < .001$, $F_2(1, 23) = 16.09$, $p < .01$). As on the previous region, there were no interaction effects, with all reading time ps > .5, and percent regressions ps > .15.

On the final region, there were no hints of any main effects or interaction effects. All ps were greater than .5, with the exception of the length effect on go-past, in the participants analysis, for which $p = .30$.

The pattern of data is clear. Contrary to the predictions based on an account of Experiment 1 that emphasizes syntactic misanalysis of the post-verbal noun phrase, there were no signs of interaction effects. The absence of a comma increased all reading time measures on ambiguous region 1 (*the vet*), but this increase was not modulated by whether there was

additional material in the subordinate clause after the verb (i.e., the effect did not depend on whether the direct object misanalysis was possible in the absence of a comma). On the subsequent region, the absence of a comma was again associated with an increase in go-past time and regressive eye movements, and again this effect was not modulated by the manipulation of the length of the subordinate clause. Indeed, it is notable that to the extent that the effect of the comma differed depending on whether the subordinate clause was long or short, on some measures (e.g., first pass on ambiguous region 1) the effect was larger in the long conditions, in which the direct object misanalysis was essentially impossible. Evidently, there is a cost associated with initiating the main clause in the absence of a comma. This conclusion accounts for the data from Experiment 2, but it also makes sense of the data from Experiment 1 and from van Gompel and Pickering's (2001) experiment. In those experiments, the critical noun phrase, in the intransitive conditions, initiated the main clause in the absence of a comma. In the transitive condition, this noun phrase was, from the point of the view of the parser, still part of the subordinate clause.

There are at least two previous results that support the notion that the absence of a comma at a subordinate clause/main clause boundary results in an increase in reading time on the main clause subject. The first comes from the comparison of the two conditions with transitive verbs in the Adams et al. (1998) experiment, which are repeated below:

(2)

c. After the dog scratched the veterinarian took off the muzzle.

d. After the dog scratched pathetically the veterinarian took off the muzzle.

Adams et al. reported a significant increase in reading time on the main clause subject (*the veterinarian*) in sentences like (2d) compared to (2c). This would be predicted on the present account, for in (2d) the reader is beginning the main clause at this point, in the absence of a comma, while in (2c) the reader is under the impression that he or she is still reading the subordinate clause. Second, an earlier unpublished experiment by Adams, Clifton, and Mitchell (1991) examined the effect of a comma on the processing of sentences like (10):

(10) While the announcer read the names(,) her assistant checked the next item on the list.

They found a highly significant increase in first pass time on the critical noun phrase (*her assistant*) when the comma was absent. (Hill & Murray, 2000, report a consistent pattern from a similar experiment.) Like the long no comma condition in the present experiment, this is a case in which is it clear to the reader that the main clause has begun, but no comma was present at the clause boundary.

A few minor points deserve brief mention. First, there was an unpredicted length effect on first pass times and go-past times in ambiguous region 2, with longer reading times in the short conditions. One plausible explanation of this finding is the frequent observation (which has rarely been explicitly studied, though see Van Dyke & Lewis, 2003) that readers tend to speed up as they progress through a sentence. But whatever the explanation may be for this length effect, it does not weaken the critical finding of disruption in the absence of a comma, and of the lack of any interaction between the two factors.

Second, some (but not all) of the comma effect may be due to a phenomenon that has been previously reported by Rayner et al. (2000) and Hirotani et al. (2006). These authors found that when a comma is present, the first fixation on the post-comma material tends to land further into this region than when a comma is absent. An additional analysis of the present data shows that this is the case here as well, with the first fixation on ambiguous region 1 landing an average of 4.56 characters into the region when the comma was absent at the end of the preceding region, and 5.01 characters into the region when the comma was present ($F_1(1, 31) = 10.40$, $p < .01$, $F_2(1, 23) = 5.31$, $p < .05$). Though this difference is significant, it is approximately half the size of the effects reported by Rayner et al. and Hirotani et al. In addition, this difference did not result in a significant difference in the number of first pass fixations on the region (1.47 vs. 1.40; $F_1(1, 31) = 2.01$, $p = .17$, $F_2(1, 23) = 2.62$, $p = .12$), so it appears that the reading time differences cannot be accounted for primarily in terms of this landing position effect. Furthermore, in the Hirotani et al. study the landing position effect did not result in reliable reading time differences on the post-comma region. (The reading time measures for this region were not reported in the Rayner et al. study). In the present study, significant differences on these measures did appear, suggesting that these effects most likely result from a process like that proposed above, wherein reading is disrupted when a comma is missing from a clause boundary at which one would be expected.

An obvious question is why the absence of a comma at the clause boundary is disruptive. One possibility is that readers' knowledge of prescriptive rules of comma usage operates quickly enough to generate this effect. However, an alternate account that has both intuitive plausibility and support from previous research would emphasize the role of prosodic factors. Several studies (e.g., Ashby & Clifton, 2005; Bader, 1998; Fodor, 2002; Steinhauer & Friederici, 2001; Stolterfoht, Friederici, Alter, & Steube, 2006) have suggested that readers impose implicit prosodic representations on written texts. Most relevant for present purposes is Steinhauer and Friederici's (2001) finding that the ERP response associated with processing a comma in silent reading is very similar to that associated with processing a prosodic boundary in a spoken sentence (i.e., the “closure positive shift”). This similarity suggests that when a comma is absent at a point at which a prosodic break would be expected, such as a subordinate clause/main clause boundary (e.g., Kjelgaard & Speer, 1999), the reader may respond in a manner similar to the manner in which he or she would respond to a prosodic violation.

Experiment 3

Experiments 1 and 2 showed that while readers do experience difficulty on a noun phrase following an intransitive subordinate clause verb, this is most likely due to difficulty associated with beginning the main clause in the absence of a comma. Given the strong comma effect in Experiment 2, and the complete absence of the critical interaction effect, there is little remaining reason to believe that readers misanalyze this noun phrase as the verb's direct object. Experiment 3 tested whether signs of such a misanalysis would appear in a different construction.

The construction tested in Experiment 3 is a *wh*-movement construction in which a constituent has been moved from its underlying position to a position earlier in the sentence.

The processing of such sentences has been a major topic of psycholinguistic investigation for several decades (e.g., Aoshima, Phillips, & Weinberg, 2004; Boland, Tanenhaus, Garnsey, & Carlson, 1995; Crain & Fodor, 1985; Fodor, 1978, 1989; Clifton & Frazier, 1989; Frazier & Clifton, 1989; Garnsey, Tanenhaus, & Chapman, 1989; Pickering & Traxler, 2001, 2003; Stowe, 1986; Traxler & Pickering, 1996). Questions and relative clauses both involve *wh*-movement. The present experiment investigated relative clauses, e.g.:

(11) The dog [that]$_i$ the woman trained t_i learned how to follow a scent.

On the standard syntactic analysis, the relative pronoun (*that*) has moved from its underlying position, leaving in this position a trace of movement (known as a *gap* in the psycholinguistic literature; the moved constituent itself is known as a *filler*) (though cf. Pickering & Barry, 1991). As a reader or listener processes a relative clause, he or she must identify the location of the gap in order to determine the role that the filler plays in the meaning of the sentence.

Much of the psycholinguistic research on *wh*-movement has focused on the question of how the processor deals with the fact that the location of the gap may be temporarily ambiguous, as in (12a–b):

(12)

a. The letter [that]$_i$ Nixon wrote t_i to Kissinger caused an uproar.

b. The letter [that]$_i$ Nixon wrote to Kissinger about t_i caused an uproar.

In (12a), the correct gap position is after *wrote*: Nixon wrote the letter in question. In (12b), on the other hand, the correct gap position is after *about*: Nixon did not write the letter, rather, he wrote about it. The reader cannot know until he or she encounters the word *caused* which of these analyses is correct. In fact, the bulk of the evidence indicates that the parser initially posits the gap in a very “eager” manner, in the first location that is licensed by the grammar, rather than waiting for certainty (e.g., Crain & Fodor, 1985; Frazier & Clifton, 1989; Pickering & Traxler, 2003; Stowe, 1986; Traxler & Pickering, 1996; but cf. Boland et al., 1995, Pickering & Traxler, 2001). Processing difficulty would be expected in a sentence like (12b) in which an early gap position is available to the parser, but ultimately turns out to be incorrect. In this case, some syntactic reanalysis is necessary.

Several previous studies have found that when a noun phrase filler is not a plausible object for the first verb that could license a direct object gap (e.g., *wrote* in 10a–b), processing disruption appears on this verb.[4] The first study of this sort was an ERP study by Garnsey et al. (1989) which found an increase in the amplitude of the N400 component at the point of reading the final verb (*called*) in a sentence like (13):

(13) The businessman knew which article the secretary called at home.

Garnsey et al. interpreted this result as reflecting the rapid detection of the implausibility that follows from an analysis on which, e.g., the secretary called the article. While it could be argued that this effect was influenced by the very slow word-by-word presentation used in the Garnsey et al. study, a similar effect was obtained in normal reading by Traxler and

Pickering (1996). In one experiment, they found a significant first fixation and gaze duration penalty on the critical verb (*shot*) in sentences like (14b), compared to (14a):

(14)

a. That's the pistol with which the heartless killer shot…

b. That's the garage with which the heartless killer shot…

In a second experiment, they found a first fixation and first pass penalty on the region corresponding to *wrote unceasingly* in (15b), compared to (15a):

(15)

a. We like the book that the author wrote unceasingly and….

b. We like the city that the author wrote unceasingly and…

This effect was replicated once again by Pickering and Traxler (2003), who found a first pass penalty (first fixation duration was not reported in this study) for the region corresponding to *landed carefully* in (16b), compared to (16a):

(16)

a. That's the plane that the pilot landed carefully behind in…

b. That's the truck that the pilot landed carefully behind in…

These findings suggest that once a filler has been identified, the first gap-licensing verb that is encountered induces the parser to posit a direct object gap. The plausibility of the interpretation that follows from this syntactic analysis is computed very rapidly, and if this interpretation is implausible (e.g., writing a city, landing a truck), an immediate effect is seen in the ERP or eye movement record.

Notably, the critical verbs in the Pickering and Traxler (2003) eyetracking study (e.g., *land*) were biased to take a prepositional phrase complement rather than a noun phrase complement, suggesting that the parser's eager gap-positing strategy is not overridden by verb bias. Indeed, two self-paced reading studies reported by Pickering and Traxler (2003) failed to find significant differences between the behavior of relative clause verbs that occur more frequently with a noun phrase complement than with a prepositional phrase complement (NP-preference verbs) and those that occur more frequently with a prepositional phrase complement (PP-preference verbs). This finding is notable in part because it contradicts an earlier finding by Stowe, Tanenhaus, and Carlson (1991), who conducted a self-paced reading experiment in which an implausible direct object gap caused difficulty only for NP-preference verbs.

One goal of the present experiment was to assess the reliability of Pickering and Traxler's (2003) finding regarding the behavior of NP-preference and PP-preference verbs in a filler-gap construction. Equally importantly, this experiment was also designed to assess whether readers experience processing difficulty when they encounter a relative clause verb that does not license a direct object gap at all, namely an unaccusative intransitive. If the parser does initially posit a direct object gap when it encounters an unaccusative relative clause verb,

reanalysis would be necessary and some disruption would be expected. If, on the other hand, strict intransitivity prevents the parser from positing a direct object gap, no disruption should appear in this condition, in contrast to similar sentences with NP-preference and PP-preference relative clause verbs.

Method

Participants—Thirty native speakers of American English, who were members of the University of Massachusetts community, were given course credit or were paid $7 to participate in the experiment. All had normal or corrected-to-normal vision, and all were naïve to the purpose of the experiment.

Materials—Because the present experiment made use of some strictly intransitive verbs, it was not possible to replicate the exact design of the studies discussed above, in which the plausibility of a direct object gap was manipulated by holding the verb constant and varying the preceding noun phrase. Instead, identical lexical material was included either in a relative clause or a main clause (which will be referred to as the *gap* and *no gap* conditions, respectively). Verb type was also varied, with twelve items making use of NP-preference, PP-preference, and unaccusative verbs, for a total of 36 items. Examples of NP-preference, PP-preference, and unaccusative sentence pairs are shown in (17) – (19) below, with the material that was identical between the gap condition (*a* versions) and no gap condition (*b* versions) in italics.

(17)

a. The gadget that *the manager called occasionally about* after the accident still didn't work. (NP-preference gap)

b. *The manager called occasionally about* the gadget after the accident. (NP-preference no gap)

(18)

a. The truck that *the pilot landed carefully behind* in the fog shouldn't have been on the runway. (PP-preference gap)

b. *The pilot landed carefully behind* the truck in the fog. (PP-preference no gap)

(19)

a. The party that *the student arrived promptly for* at the fraternity house was late in getting started. (Uunaccusative gap)

b. *The student arrived promptly for* the party at the fraternity house. (Unaccusative no gap)

The true gap site in the (a) versions was always after a post-verbal adverb and preposition. In the gap condition of the NP-preference and PP-preference sentences, the filler (*the gadget*, *the truck*) was always an implausible object for the relative clause verb (*called*, *landed*). In the gap condition of the unaccusative sentences, a post-verbal gap was ruled out by the strict intransitivity of the verb.

The twelve NP-preference and twelve PP-preference verbs were selected from the fourteen of each type used by Pickering and Traxler (2003), by excluding the two least-biased examples of each of these classes based on Pickering and Traxler's sentence completion norms. Based on these norms, the twelve NP-preference verbs used in the present experiment have a mean probability of occuring with a direct object of .72, ranging from .45 to .90. The twelve PP-preference verbs have a mean probability of occurring with a direct object of .12, ranging from 0 to .35.

The gap versions of the NP-preference and PP-preference sentences were slightly modified versions of Pickering and Traxler's (2003) original sentences with these verbs. The primary modification was to change half of the items from the "That's the *x* that…" construction that Pickering and Traxler employed (see (16) above) to a standard relative clause construction. The purpose of this change was simply to reduce the salience of this somewhat unusual construction. If Pickering and Traxler's (2003) results are indeed reliable, disruption should appear on the verb in the gap condition for both NP-preference and PP-preference verbs, compared to the no gap condition. It is at this point that the parser is assumed to entertain the object gap analysis (regardless of verb bias), and then to have to reanalyze. A main question of interest was whether a similar pattern would appear in the comparison of the gap and no gap conditions for the unaccusative sentences.

The 36 items were randomly sorted into two lists, with each list containing one version of each item and twelve sentences with each of the three verb types, with these twelve consisting of six sentences in the gap condition and six in the no gap condition. Each participant was randomly assigned to one of the two lists. The 36 experimental items were intermixed with 64 filler items; of these fillers, 28 were from an unrelated experiment, while 36 were designed specifically as fillers for the present experiment. Eighteen of these 36 filler items consisted of simple transitive sentences, and 18 consisted of relative clause sentences with a direct object gap. The sentences were presented in an individually randomized order to each participant, after eight practice trials.

Procedure—The procedure was similar to Experiments 1 and 2, except that this experiment was run using an SR Research Eyelink 1000 tracker. No bite plate is necessary with this tracker, as the participant's head is stabilized by a chin rest and a forehead rest. The sampling rate was 1000 Hz, and only the right eye was monitored. All sentences were displayed on a single line with a maximum length of 101 characters. Stimuli were displayed on a 17-inch Viewsonic monitor. Participants were seated 60 cm from the computer screen. At this distance, 3.2 characters subtended 1° of visual angle; the eyetracker has an angular resolution of 10–30 min of arc. Comprehension was checked after 40% of trials, and participants averaged 92% correct on the comprehension questions, with no participant scoring below 83%. The duration of the experiment was 30 minutes.

Results and Discussion

For the purpose of analysis of the eye movement data, sentences were divided into regions as shown below.

(20)

a. The gadget that/ the manager/ called/ occasionally about/ after the accident still didn't work.

b. The manager/ called/ occasionally about/ the gadget after the accident.

The only regions for which it was possible to carry out meaningful comparisons in this experiment were those that remained constant across the two conditions, namely regions 2–4 of the (a) version and 1–3 of the (b) version, which will be referred to as the *pre-verb* region, *verb* region, and *post-verb* region respectively.

It is important to note that effects of the gap vs. no gap manipulation are likely to appear on the pre-verb region simply because this region begins the sentence in the no gap condition. Analysis of this region was conducted primarily to rule out an interaction effect that would compromise interpretation of the data from the later regions. Furthermore, main effects of verb type were not of interest in the present experiment, and consequently the length of the critical regions was allowed to vary between verb types. In fact, the length of the verb was marginally different between conditions, with mean lengths of 5.75, 6.83, and 7.67 for the NP-preference, PP-preference, and unaccusative verbs respectively ($F_2(2, 33) = 2.89$, $p = .07$). Furthermore, the length of the post-verb region varied significantly between conditions (though in the opposite direction) with mean lengths of 17.50, 15.58, and 13.67 characters for NP-preference, PP-preference, and unaccusative items respectively ($F_2(2, 33) = 14.76$, $p < .001$). The relevant analyses on these regions are restricted to effects of the gap vs. no gap manipulation, and interactions between this manipulation and verb type.

The same four basic reading time measures were computed as in Experiments 1 and 2. Just under 3% of trials were deleted due to track losses, and less than 2% of remaining fixations were deleted due to falling outside the 80–800 ms range.

Table 3 presents the participant means on each measure for each of the critical regions, as well as the standard errors of these means. As in Experiments 1 and 2, ANOVAs were performed with participants (F_1) and items (F_2) as random variables. The gap vs. no gap manipulation was a within-participants and within-items factor, while verb type was a within-participants but between-items factor.

On the pre-verb region, there was a significant effect of the gap vs. no-gap manipulation on both first fixation and first pass time, resulting from longer times in the gap conditions (First fixation: $F_1(1, 29) = 17.32$, $p < .001$; $F_2(1, 33) = 17.29$, $p < .001$. First pass: $F_1(1, 29) = 35.35$, $p < .001$; $F_2(1, 33) = 63.49$, $p < .001$). As noted above, these differences are likely due simply to differences in linear position. There were no effects of type (ps > .2) and no interaction effects (ps > .4) on these measures. Because no regressions were possible from this region in the no-gap conditions, analysis of go-past time and percent regressions is appropriate only for the gap conditions. There were no significant differences on these measures between the three gap conditions (all ps > .3).

Turning to the verb region, there was a significant effect of verb type on the gaze duration and go-past measures, with the differences in means corresponding to the length differences noted above. More interestingly, there was a significant effect of the gap manipulation on

the duration of the first fixation on the verb, with longer times overall in the gap than in the no gap conditions ($F_1(1, 29) = 8.68$, $p < .01$; $F_2(1, 33) = 5.22$, $p < .02$). However, interpretation of this effect must be qualified by the presence of a significant interaction between gap and verb type ($F_1(2, 58) = 4.45$, $p < .02$; $F_2(2, 33) = 3.50$, $p < .05$). For the NP-preference and PP-preference verbs, first fixation duration was longer in the gap conditions than in the no gap conditions (259 ms vs. 244 ms, averaged across the two verb types), while for the unaccusative verbs, first fixation duration was actually shorter in the gap condition (267 ms vs. 280 ms). Focusing just on the NP-preference and PP-preference items, there was a significant effect of the gap manipulation ($F_1(1, 29) = 7.37$, $p < .02$; $F_2(1, 22) = 5.71$, $p < .05$), and no hint of an interaction between gap and verb type (ps > .3). Focusing just on the unaccusative items, the 13 ms reduction in first fixation duration in the gap condition was not significant ($t_1(29) = 1.30$, $p = .21$; $t_2(11) = 1.42$, $p = .18$).

On the gaze duration measure on the verb, there was no hint of an effect of the gap manipulation (ps > .9), while the interaction effect observed in first fixation duration was only marginally significant in gaze duration ($F_1(2, 58) = 2.35$, $p = .11$; $F_2(2, 33) = 2.61$, $p = .09$). The numerical size of the interaction effect was actually larger in gaze duration than in first fixation duration, so the lack of significance is due to increased variability on this measure. It is important to note that while the effect of the gap structure on first fixation duration was numerically larger for the NP-preference items than for the PP-preference items (22 ms vs. 9 ms), this difference reversed direction in gaze duration (9 ms vs. 20 ms). There were no significant effects of the gap vs. no gap manipulation and no significant interaction effects on either the go-past or percent regressions measure (all ps > .2, except for the interaction effect on percent regressions: $F_1(2, 58) = 2.82$, $p = .07$; $F_2(2, 33) = 3.16$, $p = .06$).

On the post-verb region, there were again significant effects of verb type on the first pass and go-past measures, with the means closely tracking the length differences (i.e., the differences are in the opposite direction from those found on the verb region). There was a marginal effect of the gap manipulation on the first fixation measure ($F_1(1, 29) = 3.83$, $p = .06$; $F_2(1, 33) = 3.22$, $p = .08$), and no interaction effect (ps > .4). However, it is worth noting the for the NP-preference items, the first fixation on this region was 17 ms longer in the gap condition, and for the PP-preference items it was 15 ms longer; restricting the analysis to just these items, the gap effect is fully significant in the participants analysis ($F_1(1, 29) = 6.48$, $p < .02$; $F_2(1, 22) = 3.57$, $p = .07$). For the unaccusative items, by contrast, first fixation was only 2 ms longer in the gap condition than in the no gap condition.

On the first pass measure on the post-verb region, there was no hint of a gap effect and no hint of an interaction (ps > .6). On the go-past measure there was a significant gap effect, with longer times in the gap conditions ($F_1(1, 29) = 10.42$, $p < .01$; $F_2(1, 33) = 5.96$, $p < .05$). There was no interaction between gap and verb type (ps > .3). The significant effect of the gap manipulation should be interpreted with caution; because there were no differences in first pass time or percent regressions (see below), the increase in go-past time in the gap conditions can only have resulted from more time spent re-reading earlier material on those trials on which a regression was made. This would be expected, since there is more preceding material to re-read in the gap condition. Finally, there were no significant effects

on the percent regressions measure (*p*s > .3, with the exception of the type effect: $F_1(2, 58) = 2.82$, $p = .07$; $F_2(2, 33) = 1.36$, $p = .27$).

The results of this experiment can be summarized as follows. When the critical relative clause verb was an NP-preference or PP-preference verb, the first fixation on this verb was significantly longer in the gap structure than in the no gap structure. Gaze duration on this verb was also longer in the gap condition, as was the first fixation on the next word, though these latter differences didn't reach full significance. These results are consistent with the finding (Garnsey et al., 1989; Pickering & Traxler, 2003; Traxler & Pickering, 1996) that when the filler in a relative clause construction is an implausible object for the relative clause verb, there is immediate processing disruption on this verb. Furthermore, the lack of an interaction between verb bias and the gap manipulation suggests that verb bias does not play a major role in the parser's decision about whether to posit a direct object gap in such a construction (cf. Stowe et al., 1991); while the first fixation effect on the verb was numerically larger for the NP-preference verbs, the difference in gaze duration was numerically larger for the PP-preference verbs.

Matters were very different when the critical verb was an unaccusative. With these verbs, there was no hint of difficulty in the gap condition; in fact, the first fixation and gaze durations on the unaccusative verbs were (non-significantly) shorter in the gap condition than in the no-gap condition, resulting in a significant interaction of the gap manipulation with verb type. Evidently, the parser does not posit a direct object gap when the verb does not license such a gap due to its underlying syntax. This conclusion reinforces the conclusion of Experiment 2 that the parser does not attempt to attach a noun phrase as the direct object of a strictly intransitive verb.

The pattern of data from this experiment warrants several additional remarks. First, it may be noted that the effect of an implausible direct object gap analysis in the NP-preference and PP-preference items was relatively small and quite short-lived, compared to the effects on gaze duration/first pass time that were obtained in previous eyetracking studies (Pickering & Traxler, 2003; Traxler & Pickering, 1996). One possible explanation for this finding is that the control condition in the present experiment was not a completely neutral baseline. Rather, it is possible that reading times in this condition are slightly inflated compared to the control used in the earlier studies, in which a plausible filler preceded the critical material. Some evidence for this account comes from the fact that reading times on the unaccusative verbs were substantially shorter in the gap condition than in the no gap condition, if not significantly so.

A second important point is that this is at least the third experiment to report significant increases in first fixation duration on a verb based on an implausible gap assignment (Traxler & Pickering, 1996, Experiments 1 and 2). This stands in sharp contrast to the findings of Rayner, Warren, Juhasz, and Liversedge (2004), who explicitly set out to investigate the time course with which plausibility violations affect eye movements. This study found no effects earlier than gaze duration, even in a condition involving rather extreme violations (e.g., John used the pump to inflate the large carrots for dinner). Further experiments in our own laboratory have also generally failed to find first fixation effects

when the implausibility occurs on an object nominal that has not undergone movement, as in the example above. This difference in time course calls out for explicit investigation, but one possibility is that the “eagerness” with which the parser searches for a gap site once it encounters a filler (e.g., Clifton & Frazier, 1989) speeds the process of detecting an implausible verb-object relation.

Finally, the results of the present experiment can be seen as complementary to the results obtained by Boland et al. (1995) in a self-paced reading experiment and Pickering and Traxler (2001) in both self-paced reading and eyetracking. These studies found that when the critical verb in a structure like the one tested here can take either a clausal complement or a noun phrase complement (e.g., *persuade*, *remind*) an implausible object gap does not result in significant processing difficulty. In other words, both the present experiment and these previous experiments have shown that the parser has very rapid access to the verb's argument structure: a) when the verb doesn't allow a noun phrase complement, the parser doesn't initially posit a direct object gap, and b) when the verb can occur with either a direct object or a clausal complement, the parser doesn't initially posit a direct object gap.

General Discussion

The goal of the experiments presented here was to settle the question of whether the parser attempts to analyze a noun phrase as the direct object of a verb even when the verb is clearly intransitive. In Experiments 1 and 2, the critical noun phrase was the subject of the main clause of the sentence and followed an intransitive subordinate clause verb. In Experiment 3, the critical noun phrase was modified by a relative clause whose initial verb was intransitive. The results are exceptionally clear. Disruption does reliably appear on the critical noun phrase in the first of these constructions, even when the verb prohibits a direct object due to its underlying syntax. However, this disruption appears whenever a comma is absent from the clause boundary, even when syntactic misanalysis is impossible because additional material intervenes between the verb and the critical noun phrase. The possibility of syntactic misanalysis does not add to this processing difficulty. In the relative clause construction there were no signs of difficulty on an intransitive verb, in contrast to the difficulty observed with optionally transitive verbs when a direct object gap is implausible. This result suggests that the parser does not posit a direct object gap after an intransitive verb.

The general conclusion that can be drawn from these results is that the parser does not ignore subcategorization restrictions imposed by the verb. In the construction tested in Experiments 1 and 2, these subcategorization restrictions are used by the parser to rule out attaching the post-verbal noun phrase as a direct object, and in Experiment 3, they are used to rule out positioning a direct object gap after the critical verb. It remains theoretically possible that the parser does entertain the illegal direct object analysis, but if so, no trace of this difficulty is manifested in the eye movement record.

The finding that the absence of a comma at the subordinate clause/main clause boundary increases reading time for the main clause subject is relevant to the interpretation of several experimental results other than those that are the direct target of this article. In an

eyetracking experiment closely related to the topic of this article, Pickering, Traxler, & Crocker (2000, Experiment 3) tested sentences like the following:

(21)

a. While the pilot was flying the plane that had arrived stood over by the fence.

b. While the pilot was flying the horse that had arrived stood over by the fence.

The purpose of this experiment was to determine whether readers adopt the direct object analysis of a post-verbal noun phrase (*the plane that had arrived*/*the horse that had arrived*) even when the preceding verb is preferentially intransitive, like *fly*. The pattern of results is similar to that obtained in Experiment 1, and in van Gompel and Pickering's (2001) experiment, with longer reading times on the critical noun phrase when it is an implausible direct object, as in (21b), and clear disruption on the disambiguating verb when the critical noun phrase is a plausible direct object (21a). Pickering et al. interpreted this crossover pattern as suggesting that readers adopt the direct object analysis in both cases, and are forced to reanalyze either by implausibility (in 21b) or by syntactic disambiguation (in 21a). But in light of the present results, it seems that the claim that readers are adopting the direct object analysis in (21b) should be reconsidered. The longer reading times on the post-verbal noun phrase may have resulted from the absence of a comma at the clause boundary. It is worth noting that this does not undermine the claim that readers are adopting the direct object analysis in (21a), since in this case the evidence takes the form of longer reading times starting on the disambiguating main clause verb. In sum, while it can still be concluded from the Pickering et al. (2000) experiment that readers adopt the direct object analysis when the verb is preferentially intransitive and the post-verbal noun phrase is a plausible object (as in 21a), it is less clear whether readers adopt this analysis when the verb is preferentially intransitive and the critical noun phrase is an implausible object (as in 21b).

Pickering et al.'s (2000) experiment is closely related to an earlier series of experiments conducted by Pickering and Traxler (1998) in which the plausibility of a post-verbal noun phrase as a direct object was manipulated. In their Experiment 1, for example, participants read sentences like (22a–d):

(22)

a. As the woman edited the magazine about fishing amused all the reporters.

b. As the woman sailed the magazine about fishing amused all the reporters.

c. As the woman edited, the magazine about fishing amused all the reporters.

d. As the woman sailed, the magazine about fishing amused all the reporters.

Reading times on the post-verbal noun phrase (*the magazine about fishing*) were inflated in (b) compared to (d), but not in (a) compared to (c). Pickering and Traxler (1998) interpreted this result as reflecting the parser's initial analysis of this noun phrase as the object of *sailed*, and the subsequent need to reanalyze. On this basis, they argued that implausibility does not deter the parser from initially constructing the direct object analysis. Again, however, the results from Experiment 2 of the present study suggest an alternate interpretation. The increased reading time on *the magazine about fishing* in (22b) may be due, once again, to a

general slowing that occurs at the beginning of the main clause when a comma is absent from the clause boundary. To eliminate this possibility, it would be necessary to show that the disruption on this noun phrase is larger in (22b) than in a corresponding sentence in which the comma is missing, but in which the direct object misanalysis is impossible, e.g., As the woman sailed past the dock the magazine about fishing amused all the reporters. It is, of course, an empirical question whether this is the case.

It should be noted that the "missing comma" explanation for the results obtained by Pickering et al. (2000) and Pickering and Traxler (1998) clearly does not extend to their experiments on the direct object/sentence complement ambiguity (e.g., *The young athlete realized her potential*&; Pickering et al., Experiments 1 and 2; Pickering & Traxler, Experiment 2). These experiments demonstrated a tendency to analyze a post-verbal noun phrase as a direct object when the verb more frequently takes a sentence complement, and also when the resulting analysis is implausible. In this construction, no comma would be expected before the critical noun phrase, on either analysis. Interestingly, Sturt, Pickering, and Crocker (1999) have demonstrated that recovery from the subordinate clause object/ main clause subject garden path is more difficult than recovery from the direct object/ sentence complement garden path. If the comma is indeed a marker of an implicit prosodic boundary, and if structural reanalysis is especially difficult when prosodic reanalysis is also required (Bader, 1998), this pattern of results would be expected.

The results of Experiment 3, however, reinforce the standard interpretation of the previous studies (Garnsey et al., 1989; Pickering and Traxler, 2003; Traxler & Pickering, 1996) that have found evidence of processing difficulty when a noun phrase filler is an implausible object for the first gap-licensing verb that the reader encounters. This effect has been regarded as evidence that the parser immediately posits a direct object gap without regard to plausibility, then notes the implausibility of the resulting analysis. Experiment 3 reinforces this conclusion by showing that when the parser does not posit a direct object gap upon encountering the verb (because the verb does not allow an object), no processing difficulty results.

Conclusion

The present experiments eliminate the apparent challenge to constraint satisfaction parsing theories (MacDonald et al., 1994; McRae et al., 1998) from the Mitchell (1987) and van Gompel and Pickering (2001) results. According to this family of theories, the parser's initial analysis results from competition between alternatives, each of which may be supported to varying degrees by information from multiple sources. The subcategorization restrictions associated with the verb are one source of information affecting the level of activation of competing analyses. On this view, an illegal direct object analysis may be activated along with the ultimately correct analysis, but this illegal analysis is suppressed very rapidly by the very strong information coming from the verb.

The garden path model (Frazier, 1978, 1987) can also accommodate the present results. This model asserts that the analysis that is initially constructed is the one that, of the available alternatives, satisfies the strategies of minimal attachment and late closure, as well as the

Minimal Chain Principle/Active Filler Strategy (De Vincenzi, 1991; Clifton & Frazier, 1989). In the construction tested in Experiments 1 and 2, late closure predicts a preference to attach the post-verbal noun phrase as the verb's direct object, when this analysis is available. In order to account for the present results, the garden path model must assume that the subcategorization restrictions imposed by the verb rule out the direct object analysis from the parser's set of possible choices (contrary to the tentative conclusion advanced by Frazier, 1989). Similarly, the Minimal Chain Principle/Active Filler Strategy predicts a direct object gap in the construction tested in Experiment 3, when one is available, since these principles propose that the parser ranks the option of a gap site above all other possibilities, once a filler has been identified. Again, the garden path model must assume that the verb's subcategorization restrictions are accessed so rapidly, upon reading the verb, that the direct object analysis is not even considered. The claim that the parser has essentially immediate access to the subcategorization restrictions that are encoded in the verb's lexical entry is a substantive empirical claim, and requires further investigation.

Where the two views make clearly divergent predictions is with respect to the role of subcategorization *biases* (i.e., the frequency with which a verb appears with each of the syntactic argument types that it allows), as opposed to subcategorization *restrictions*. According to the garden path model, biases should play no role in the selection of an initial analysis; if two subcategorization frames are available, the selection of an analysis will be made on structural grounds, without regard to frequency. In fact, it appears that this is at least sometimes the case. As noted above, there is evidence that the parser does preferentially adopt the subordinate clause object analysis over the main clause subject analysis when the subordinate clause verb is intransitive-biased, at least when the critical noun phrase is a plausible object (Pickering et al., 2000, Experiment 3). Experiment 3 of the present study reinforces the conclusion that the parser does posit a direct object gap after a verb that is intransitive-biased (Pickering & Traxler, 2003). In addition, there is conflicting evidence in the eye movement literature about whether the relative frequency with which a verb takes a direct object or a sentence complement influences the probability that the parser will analyze a post-verbal noun phrase as a direct object; some studies have found an effect of frequency (Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Trueswell, Tanenhaus, & Kello, 1993), while at least as many others have not (Ferreira & Henderson, 1990; Pickering et al., 2000; Kennison, 2001). Finally, Staub, Clifton, & Frazier (2006) found that when a sentence is ambiguous between a heavy NP shift analysis and an intransitive analysis, readers prefer an intransitive analysis as long as the verb allows an intransitive frame, regardless of transitivity bias. On the other hand, readers are quick to adopt the heavy NP shift analysis when the verb is obligatorily transitive. In sum, it appears that the parser will not adopt a syntactic analysis that requires violating the verb's subcategorization restrictions, but it sometimes prefers an analysis in which the verb appears in a low-frequency subcategorization frame. In fact, this position has been articulated very clearly by Ferreira and McClure (1997). In a passage directly foreshadowing the present results, these authors suggested that:

> only structures permitted by a verb are created, but all permitted structures are equally viable. For example, given a string such as *After Mary arrived Bill*…the direct object analysis would not be created because *arrive* does not include an

> argument structure allowing a direct object. But for a string such as *Because Mary walked the meeting*…, the direct object analysis would be constructed both because of the late closure principle and because the transitive structure is allowed by the verb – crucially, even though the transitive structure is less frequent than other alternatives (and despite the anomalous nature of the phrase *walked the meeting*) (p. 277).

From a constraint satisfaction perspective, it is not clear why subcategorization restrictions and subcategorization biases should behave differently, since the mechanisms by which each type of information have their effects would seem to be identical. In general, it is not obvious whether this framework has room for a categorical distinction between a syntactic analysis that is ungrammatical and one that is merely very low in frequency. The constraint satisfaction framework provides no clear role for the grammar, as this notion is usually defined in terms of the language user's knowledge of the rules and principles that generate all and only the sentences of his or her language (e.g., Chomsky, 1986). Of course, depending on one's theoretical orientation, the idea that the parser need not make use of a grammar may appear to be a benefit or a drawback.

A final question that emerges from the present results is why unergative verbs behave like pure intransitives, rather than like verbs with merely a very strong intransitive bias. There are at least a few constructions in which unergative verbs do appear to allow a direct object (4a–c above), and as just noted, it has been previously shown that the parser may attempt a direct object analysis with intransitive-biased verbs. The conclusion from the present experiments, however, is that the parser does not attempt a direct object analysis with either unaccusatives or unergatives. There are at least two plausible answers to this question. First, it is possible that there is effectively some lower frequency bound below which the parser does not consider the direct object analysis. As van Gompel and Pickering (2001) noted, the constructions in (4a–c) are very low frequency indeed. A more interesting, and more theoretically motivated, possibility is that the apparent direct object in (4a–c) is not actually a direct object. It is notable that at least in the case of the its way and resultative constructions, the sentence is ungrammatical without the final prepositional phrase (i.e., **The speaker laughed her way*. and **The child sneezed the paper*.) Levin and Rappaport Hovav (1995), among others, have suggested an analysis of these constructions on which the post-verbal noun-phrase and the subsequent prepositional phrase actually constitute a clausal complement (a so-called “small clause”) to the unergative verb. If this is the correct synactic analysis of these constructions, then what the experiments presented here demonstrate is that the parser prefers an intransitive analysis over an analysis on which an unergative verb takes a low-frequency clausal complement.

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Appendix A

Materials in Experiment 1. The text that varied based on experimental condition is enclosed in parentheses, and the three versions are separated by the vertical pipe (|), in the order (unaccusative|unergative|transitive).

As the gangster (died|laughed|shot) his wife and young daughters burst into hysterics.

When the dog (arrived|struggled|scratched) the vet and his new assistant took off the muzzle.

As the ship (receded|drifted|sailed) the waters of the Atlantic Ocean remained blue and calm.

After the pilgrims (arrived|prayed|begged) the Indians who sat by the fire lit a peace pipe.

Though the swimmer (prospered|sulked|phoned) the coach of the team refused to congratulate him.

While the crowd (swelled|screamed|applauded) the performer in the bizarre outfit rested backstage.

While the audience (remained|roared|cheered) the magician with the elegant cape waved his baton.

While the students (remained|gossiped|gobbled) the desserts that looked so delicious were removed.

When the instructor (vanished|talked|taught) the visitors from the other school lost interest.

Because the crying baby (departed|squirmed|clutched) the woman and her friend stayed until the end.

Although the manager (departed|yawned|booed) the comedian who told bad jokes began his act.

After the patient (appeared|coughed|asked) the nurse who was very caring told her the news.

After the lifeguard (rose|smiled|visited) the swimmers who were waiting jumped into the pond.

After the rooster (arose|crowed|woke) the farmer and the young boy went to the hen house.

As the class (deteriorated|daydreamed|contemplated) the teacher of the physics class asked a question.

While the woman (persisted|gardened|decorated) the pot that had a broken handle boiled on the stove.

When the customer (erupted|complained|interrupted) the manager of the shop changed the advertisement.

As the bachelor (perished|moaned|smoked) the pipe containing his best tobacco fell to the floor.

While the prisoners (erupted|fasted|heckled) the guards who were in charge refused to negotiate.

As long as the king (prevailed|thundered|governed) his subjects and followers feared his wrath.

After the host (disappeared|shrieked|interrupted) the discussion of the issue became more interesting.

After the woman (emerged|bowed|dressed) her children and her husband thought she looked lovely.

After the soldier (fainted|argued|saluted) the doctor attending the exercise ordered it to stop.

As the guard (swooned|tiptoed|bluffed) the thieves who were wearing masks grabbed the money.

Appendix B

Materials in Experiment 2. The text that varied based on experimental condition is enclosed in parentheses, and the four versions are separated by the vertical pipe (|), in the order (no comma short|comma short|no comma long|comma long).

When the dog (arrived|arrived,|arrived at the clinic|arrived at the clinic,) the vet and his assistant went home.

Because the crying baby (departed|departed,|departed at noon|departed at noon,) the woman and her friend stayed.

As the gangster (died|died,|died on the couch|died on the couch,) his wife and young daughters wept.

After the patient (appeared|appeared,|appeared in the room|appeared in the room,) the nurse in the blue hat left.

While the prisoners (erupted|erupted,|erupted in a riot|erupted in a riot,) the guards in the prison shot in the air.

After the woman (emerged|emerged,|emerged in her dress|emerged in her dress,) her children and husband smiled at her.

After the soldier (fainted|fainted,|fainted from fright|fainted from fright,) the doctor at the base called his boss.

When the instructor (vanished|vanished,|vanished from sight|vanished from sight,) the visitors from France lost interest.

As the ship (receded|receded,|receded from sight|receded from sight,) the waters of the ocean remained calm.

As long as the king (prevailed|prevailed,|prevailed in war|prevailed in war,) his subjects and followers feared him.

While the crowd (swelled|swelled,|swelled in size|swelled in size,) the performer in the mask rested backstage.

After the host (disappeared|disappeared,|disappeared from the set|disappeared from the set,) the discussion of the issue improved.

After the pilgrims (prayed|prayed,|prayed for peace|prayed for peace,) the Indians by the fire lit a pipe.

Though the swimmer (sulked|sulked,|sulked childishly|sulked childishly,) the coach of the team congratulated him.

While the audience (roared|roared,|roared with excitement|roared with excitement,) the magician in the cape waved.

While the students (gossiped|gossiped,|gossiped noisily|gossiped noisily,) the desserts on the table were removed.

Although the manager (yawned|yawned,|yawned loudly|yawned loudly,) the comedian from Chicago began his act.

After the lifeguard (smiled|smiled,|smiled at them|smiled at them,) the swimmers who were waiting dove in.

After the rooster (crowed|crowed,|crowed at the dawn|crowed at the dawn,) the farmer and his son visited the hens.

As the students (daydreamed|daydreamed,|daydreamed quietly|daydreamed quietly,) the teacher in room 12B asked a question.

While the woman (gardened|gardened,|gardened in her yard|gardened in her yard,) the pot with a broken handle boiled over.

When the customer (complained|complained,|complained about the staff|complained about the staff,) the manager of the shop listened.

As the bachelor (moaned|moaned,|moaned in pain|moaned in pain,) the pipe with his best tobacco fell to the floor.

As the guard (tiptoed|tiptoed,|tiptoed away|tiptoed away,) the thieves in ski masks grabbed the money.

Appendix C

Materials in Experiment 3. For each item, the gap condition is listed first, followed by the no gap condition.

NP-Preference items:

The country that the soldier killed enthusiastically for during the war was not grateful.

The soldier killed enthusiastically for his country during the war.

The college that the student asked repeatedly about during orientation was very far away.

The student asked repeatedly about the college during orientation.

The gadget that the manager called occasionally about after the accident still didn't work.

The manager called occasionally about the gadget after the accident.

The field that the fisherman heard repeatedly about after fishing trips was quite a mystery.

The fisherman heard repeatedly about the field after fishing trips.

The house that the architect instructed at length about to the graduate students was a masterpiece.

The architect instructed at length about the house to the graduate students.

The corporation that the ex-con kidnapped reluctantly for after being released was very prominent.

The ex-con kidnapped reluctantly for the corporation after being released.

That's the tractor that the contractor paid excessively for because of the union contract.

The contractor paid excessively for the tractor because of the union contract.

That's the burglar that the editor read meticulously about before the meeting.

The editor read meticulously about the burglar before the meeting.

That's the carpet that the teaching assistant taught inexpertly about to the undergraduates.

The teaching assistant taught inexpertly about the carpet to the undergraduates.

That's the dock that the boy threw thoughtlessly at before being scolded.

The boy threw thoughtlessly at the dock before being scolded.

That's the fight that the old man told frequently about to the residents of the nursing home.

The old man told frequently about the fight to the residents of the nursing home.

That's the city that the young woman wrote emotionally about in her diary.

The young woman wrote emotionally about the city in her diary.

PP-Preference items:

The car that the dog worried compulsively about after the accident stayed in the driveway.

The dog worried compulsively about the car after the accident.

The props that the actor spoke briefly about to the acting coach were quite ugly.

The actor spoke briefly about the props to the acting coach.

The truck that the pilot landed carefully behind in the fog shouldn't have been on the runway.

The pilot landed carefully behind the truck in the fog.

The traitor that the courier communicated secretly about to the spy was known for treachery.

The courier communicated secretly about the traitor to the spy.

The page that the guy fished repeatedly for in his atlas had a map of the mountain.

The guy fished repeatedly for the page in his atlas.

The river that the child pointed excitedly toward this morning flowed by the campground.

The child pointed excitedly toward the river this morning.

That's the pit that Dale Earnhardt raced skillfully past near the end of the race.

Dale Earnhardt raced skillfully past the pit near the end of the race.

That's the weapon that the policeman searched rapidly for in the alley.

The policeman searched rapidly for the weapon in the alley.

Those are the animals that the protestors shouted loudly about at the meeting.

The protestors shouted loudly about the animals at the meeting.

That's the factory that the trucker traveled rapidly toward after picking up a load.

The trucker traveled rapidly toward the factory after picking up a load.

That's the bomb that the lawyer argued heatedly about during the trial.

The lawyer argued heatedly about the bomb during the trial.

That's the tank that the soldier swore emphatically about to the sergeant.

The soldier swore emphatically about the tank to the sergeant.

Unaccusative items:

The party that the student arrived promptly for at the fraternity house was late in getting started.

The student arrived promptly for the party at the fraternity house.

The suit that the speaker appeared reluctantly in for the conference was very hot and itchy.

The speaker appeared reluctantly in the suit for the conference.

The virus that the teenager died tragically from before finishing high school was unknown to science.

The teenager died tragically from the virus before finishing high school.

The area that the visitors remained patiently in while the inmates were called was small and cramped.

The visitors remained patiently in the area while the inmates were called.

The building that the thief vanished quietly behind during the chase was a nondescript warehouse.

The thief vanished quietly behind the building during the chase.

The airport that the ambassador departed rapidly from during the unrest was closed to most traffic.

The ambassador departed rapidly from the airport during the unrest.

That's the problem that the scientist persisted diligently on for several years.

The scientist persisted diligently on the problem for several years.

That's the manager that the customer erupted angrily at near the register.

The customer erupted angrily at the manager near the register.

That's the army that the conqueror prevailed mightily over on the way to the capital.

The conqueror prevailed mightily over the army on the way to the capital.

That's the gate that the limousine emerged slowly from as it left the house.

The limousine emerged slowly from the gate as it left the house.

That's the chemical that the metal deteriorated gradually from over time.

The metal deteriorated gradually from the chemical over time.

That's the bed that the patient arose swiftly from despite her illness.

The patient arose swiftly from the bed despite her illness.

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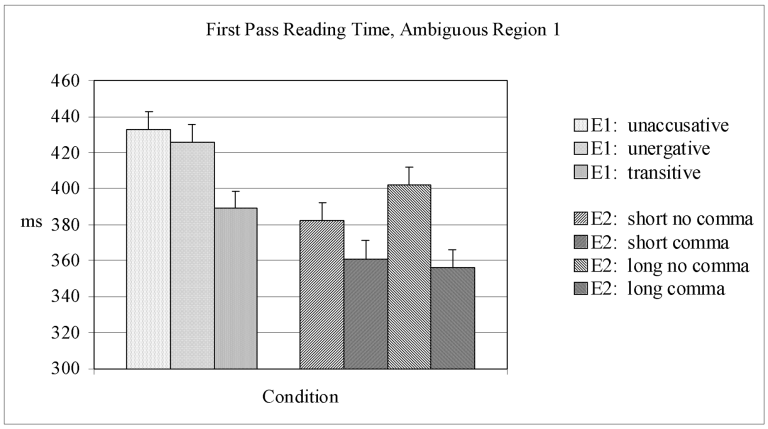

Figure 1.

Mean first pass reading time on the critical noun phrase in Experiments 1 and 2. The three left-most bars represent first pass time in each condition of Experiment 1, in which verb type was manipulated. The four right-most bars represent first pass time in each condition of Experiment 2, in which the length of the subordinate clause verb phrase and the presence or absence of a comma were manipulated; all verbs were intransitive. Error bars reflect standard error of the mean, computed according to the Masson and Loftus (2003) method for within-participant designs.

Table 1

Experiment 1 Participant Mean Reading Times, in Milliseconds, and Percent Regressions

Measure	Initial Region (*When the dog*)	Verb Region (*arrived*| *struggled*| *scratched*)	Ambiguous Region 1 (*the vet*)	Ambiguous Region 2 (*and his*)	Ambiguous Region 3 (*new assistant*)	Final Region (*took off the muzzle*.)
First Fixation Duration						
unaccusative	202 (6.3)	287 (10)	276 (7)	265 (6)	253 (6)	279 (6)
unergative	207 (5.6)	286 (9)	271 (7)	262 (6)	248 (6)	270 (6)
transitive	206 (5.2)	274 (8)	270 (8)	262 (6)	249 (6)	275 (7)
First Pass Time						
unaccusative	617 (23)	320 (13)	433 (20)	345 (12)	377 (14)	874 (33)
unergative	603 (20)	323 (13)	426 (18)	343 (12)	355 (14)	831 (28)
transitive	626 (22)	313 (12)	389 (18)	352 (12)	386 (16)	929 (39)
Go-Past Time						
unaccusative	617 (23)	345 (15)	493 (24)	433 (19)	440 (17)	1046 (62)
unergative	603 (20)	366 (16)	504 (24)	383 (17)	428 (18)	938 (38)
transitive	626 (22)	341 (13)	419 (19)	377 (16)	432 (17)	1449 (146)
Percent Regressions						
unaccusative	0	4.8 (1.5)	9.2 (1.5)	10.7 (1.9)	12.0 (2.9)	9.1 (2.2)
unergative	0	7.4 (1.8)	12.4 (2.0)	6.8 (1.6)	12.0 (2.4)	8.1 (2.1)
transitive	0	5.1 (1.2)	5.3 (1.3)	3.1 (1.0)	10.5 (2.1)	22.1 (4.3)

Note: Standard error of the mean is in parentheses.

Table 2

Experiment 2 Participant Mean Reading Times, in Milliseconds, and Percent Regressions

Measure	Initial Region (*When the dog*)	Verb Region (*arrived*|*arrived,*|*arrived at the clinic*|*arrived at the clinic,*)	Ambiguous Region 1 (*the vet*)	Ambiguous Region 2 (*and his assistant*)	Final Region (*went home.*)
First Fixation Duration					
short no comma	226 (9)	279 (7)	287 (8)	280 (13)	316 (11)
short comma	220 (6)	288 (8)	264 (7)	268 (10)	318 (12)
long no comma	214 (8)	289 (7)	279 (9)	271 (9)	318 (12)
long comma	208 (6)	290 (8)	270 (8)	268 (6)	311 (10)
First Pass Time					
short no comma	610 (20)	327 (12)	382 (16)	566 (23)	579 (25)
short comma	621 (26)	332 (18)	361 (16)	558 (28)	575 (27)
long no comma	622 (21)	731 (23)	402 (17)	521 (27)	581 (28)
long comma	602 (22)	711 (30)	356 (14)	517 (18)	583 (26)
Go-Past Time					
short no comma	610 (20)	346 (14)	451 (26)	643 (42)	728 (66)
short comma	621 (26)	351 (20)	387 (18)	586 (40)	725 (58)
long no comma	622 (21)	764 (28)	447 (20)	602 (42)	685 (45)
long comma	602 (22)	752 (33)	375 (17)	531 (20)	715 (47)
Percent Regressions					
short no comma	0	3.8 (1.3)	8.9 (2.2)	5.5 (1.9)	20.3 (3.9)
short comma	0	4.7 (1.9)	4.2 (1.5)	1.5 (0.8)	19.5 (4.8)
long no comma	0	3.1 (1.2)	5.3 (1.5)	9.6 (4.7)	19.7 (4.7)
long comma	0	4.2 (1.5)	2.5 (1.0)	2.0 (1.2)	20.2 (3.9)

Note: Standard error of the mean is in parentheses.

Table 3

Experiment 3 Participant Mean Reading Times, in Milliseconds, and Percent Regressions

Measure	Pre-verb region	Verb region	Post-verb region
First Fixation Duration			
NP pref gap	216(8)	258(9)	264(9)
NP pref no gap	195(6)	237(8)	247(9)
PP pref gap	232(8)	260(9)	264(11)
PP pref no gap	201(8)	251(8)	249(9)
Unacc gap	222(9)	267(9)	249(6)
Unacc no gap	204(9)	280(12)	247(10)
First Pass Time			
NP pref gap	366(20)	290(11)	550(37)
NP pref no gap	277(12)	281(14)	567(30)
PP pref gap	334(13)	331(17)	492(28)
PP pref no gap	280(23)	311(14)	500(31)
Unacc gap	348(19)	334(14)	418(17)
Unacc no gap	261(15)	361(19)	398(20)
Go-Past Time			
NP pref gap	500(31)	324(14)	835(62)
NP pref no gap	277(12)	350(24)	742(46)
PP pref gap	469(30)	383(19)	658(35)
PP pref no gap	280(23)	354(16)	634(36)
Unacc gap	458(30)	394(22)	570(27)
Unacc no gap	261(15)	421(24)	476(24)
Percent Regressions			
NP pref gap	24.5(4.5)	5.4(1.6)	21.3(3.2)
NP pref no gap	0	13.7(2.8)	23.6(3.8)
PP pref gap	25.4(4.8)	10.4(2.5)	20.5(3.3)
PP pref no gap	0	9.7(2.3)	17.8(2.9)
Unacc gap	21.3(3.9)	11.3(2.8)	19.2(2.8)
Unacc no gap	0	9.4(2.6)	13.1(3.0)

Note: Standard error of the mean is in parentheses.